FLICKER PREDICTION TECHNIQUES FOR SAWMILLS

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By

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Declaration

I, Ismail Jefferies declare that this work is my own original material and has not been submitted before, to this or any other institution except Cape Technikon for evaluation in obtaining the M. Tech. degree in Electrical Engineering.

I. Jefferies	05/04/2004 Date

Synopsis

The aim of the thesis is to investigate and develop a technique for predicting the flicker emission of sawmill loads. The technique makes use of an empirical formula to calculate the characteristic coefficient of a sawmill motor (K_{sm}) and depends upon the short term flicker severity level (P_{st}), load size and fault level.

Three types of sawmill loads are commonly found in South African plants, namely the Circular, Multi-rip, and Frame Saws. A sawmill plant was selected as a benchmark and K_{sm} factors for these types of saws were calculated by application of the empirical formula. These K_{sm} factors are required for predicting the flicker emitted by similar saws at other sawmill plants.

A flicker meter was used to measure the flicker values (P_{st}) for these saws. Fault levels were calculated for various sawmill sites investigated. Load sizes were determined and the empirical formula used to calculate the K_{sm} factors. These K_{sm} factors were then compared to those calculated at the benchmark sawmill in order to determine the accuracy of the empirical formula.

Nine case studies were conducted. The sawmills selected for these investigations were in different geographical forest areas in South Africa. Different K_{sm} factors were found and this can be attributed to the differences in the density and hardness of the wood in the various areas. It can also be attributed to the mechanical variables of the saws. However, a comparative analysis of the K_{sm} factors comparison reveal that many K_{sm} factors fall within a similar range and for planning purposes 88,19 and 111 can be used for the Circular, Multi-rip, and Frame Saws, respectively.

The results obtained demonstrate that the developed flicker emission prediction technique for sawmills is an effective analytical tool to be used for planning the network to ensure that the flicker levels will remain within acceptable limits.

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Abbreviations and Symbols

AC	Alternating Current
Hz	Hertz
IEC	International Electro-technical Commission
K_{sm}	Characteristic Coefficient of sawmill motors
NER	National Electricity Regulator
NRS	National Regulatory standard
P_{st}	Short Term Flicker Severity Level
P_{lt}	Long Term Flicker
PCC	Point of Common Coupling
SVC	Static VAR Compensator
UIE	Union for Electro - Heat
FM	Flicker meter
VR	Voltage recorder
EMPT	Electro-Magnetic Transient Program
EMC	Electromagnetic Compatibility
DOS	Disk Operating System
LV	Low voltage
MV	Medium voltage
rms	root-mean-square
M	Motor
ΔV	Voltage fluctuations
ΔI	Current fluctuations
Δn	Speed variation
Ø	Flywheel diameter
rpm	revolutions per minute

Chapter 1

1 Introduction

Flicker is the visual perception of variations in luminance of lighting equipment. These variations in luminance are caused by fluctuations in the rms (root mean square) voltage waveform. Utilities are faced with the challenge of providing high quality and reliable power systems. With recent improvements in technology to meet customer equipment requirements a more reliable quality of supply is expected especially from customers with very sensitive equipment. Flicker is a power quality disturbance that should be managed to ensure that the needs of the broader customer base are met [5].

The increased use of variable loads such as arc furnaces, crushers and sawmills has generated the need for better techniques to evaluate their effects on the power system. Utilities in South Africa must comply with the Electricity Act regarding the quality of supply standard, namely NRS 048 standards in terms of flicker levels [1]. The application of this standard is intended to optimize and minimize the combined cost of supply of electricity on an overall national basis. For LV and MV networks, the compatibility levels for short-term flicker is $P_{st} = 1.25$ during the daylight period from 08:00 to 16:00 and $P_{st} = 1$ during the night time period from 16:00 to 08:00 [1]. Bearing in mind that flicker mitigation techniques can be expensive for both a customer with flicker problems and for the utility, therefore a need exists for a method to predict the flicker. A utility therefore needs to predict the flicker emission of these loads on the power system to ensure future compliance.

Extensive research to date has concentrated predominately on predicting the flicker emission caused by arc furnaces and rock crushers. An EMTP-based (Electro-Magnetic Transient Program) arc furnace model was developed for the evaluation of flicker concerns associated with supplying large industrial steel mills. The model included a dynamic arc representation which is designed to be characteristic of the initial portions of the melt cycle when the arc characteristics present the worst flicker conditions [2,3,4,6,7].

The major difficulty faced in developing a furnace model is to accurately characterise the electric arc, which depends on the materials being melted. The results of the measurements on arc furnaces have resulted in an empirical relationship being developed for predicting flicker [2,3,4].

At crusher plants, the motor would accelerate and decelerate from the normal running speed, during the crushing process, due to the mechanical crushing action of the crusher. The speed variation of the motor during the crushing process, results in the variation of load current drawn by the motor. The variation in the load current gives rise to voltage fluctuations.

As no standard was is in place for predicting the flicker on non-cycling loads, a method based on the empirical formula has been used extensively for predicting the flicker of arc furnaces and crusher loads. The empirical formula accuracy has been proven to be effective on the crusher plants [6,7].

Frame Saws used at sawmill plants are loads, which are driven by motors drawing a variable load current when subjected to the sawing process. This process involves the acceleration and deceleration of the motor causing a variation in the load current and thereby the voltage fluctuations [8]. The operation of the saws at sawmill plants operate similarly to crusher plants. For this reason the empirical formula is investigated as a analytical tool for predicting the flicker emission caused by sawmills onto the network.

If effective, this prediction technique will enable the planning departments of utilities to ensure that flicker levels will not be exceeded on networks.

The empirical formula to be investigated is expressed as:

$$P_{st} = \frac{K_{sm} \times \text{Load size}}{\text{Fault level}} \tag{1.1}$$

Where;

P_{st}	= Short term flicker severity level calculated over 10 minute period
Load size	= size of the motor driving the saw in VA (Equation 1.1 being an empirical formula an assumption is made that the kW and kVA component is the same as any variation in the motor power factor will be in corperated in the K_{sm} factor) For this reason the kW nameplate ratings of the motors are being used
Fault level	= the fault level at the point of measurement in VA
K_{sm}	= Characteristic Coefficient. Refers to the electrical behaviour of the sawmill motor when exposed to the sawing process. The K_{sm} depends on the mechanical dimensions of the saw with respect to [8]:

- Flywheel size,
- different tensioning of vee-belts,
- different counter weights on the flywheels and also different speed of flywheels
- motor power factor

Research on sawmills has been limited. At present no conclusive procedure exists to predict the flicker emission of sawmills on a network. Using a empirical formula similar to that used for arc furnaces and crushers, a K_{sm} factor can be calculated for the saws. It has been proposed that K_{sm} (characteristic coefficient of sawmill motors) factors for sawmill loads can be calculated with the use an empirical formula [8]. The K_{sm} factor refers to the electrical behaviour of a sawmill motor when subjected to the sawing process.
These values need to be verified so that they can be used for predicting the flicker emitted by similar saws at other sawmills.

The objectives of the research are to investigate:

1. The accuracy of the calculated K_{sm} factors for Frame Saws and the use of an empirical formula for predicting flicker emission at sawmills.
2. The accuracy of the empirical formula on sawmill plants.
3. The impact of the mechanical variables of the saw on the flicker levels.
4. The impact of the hardness and type of wood on the flicker levels.

An overview of the thesis can be summarised as follows: Chapter 2 discusses literature reviews of research previously done, problem statement as well as a description of the loads present at the sawmills. Chapter 3 explains the developed methodology to be used in order to predict flicker emission on sawmills. Chapter 4 discusses the measurements done for all the case studies.

In Chapter 5, a comparison and analysis of the K_{sm} factors of the various plants are discussed and a statistical method is used to calculate a K_{sm} factor. The contributions and conclusions regarding the work done are discussed in Chapter 6. Future work regarding the prediction technique on sawmills is discussed in Chapter 7.

Chapter 2

2 Literature Review

In this chapter the fundamental definition of flicker and related concepts as well as how it is evaluated are discussed. The need for a flicker prediction technique for sawmills is also described. An overview of the research previously done in developing a technique for predicting flicker emission on sawmills as well as the load description is also presented.

2.1 Flicker Concepts

Flicker is a power system disturbance, which can be defined as the visual perception of variations in luminance of lighting equipment. These variations are caused by the fluctuations in the supply voltage. For voltage deviations the change is usually expressed as $\Delta V/V$. The fluctuations are characterised by the magnitude of the voltage changes and the frequency with which they occur. The human visual system reacts differently to light with reference to its frequency of voltage deviations. Flicker gives rise to visual discomfort and can lead to complaints from the customer to the utility. Flicker is evaluated in terms of a P_{st} (Short Term Flicker Severity). The threshold at which flicker becomes perceptible to the human eye is at a $P_{st} = 1$. The human eye is particularly sensitive to the variations in luminance in lighting equipment, in the region of 8 – 10Hz. [7]

The voltage fluctuations are caused by the fluctuating load current drawn by variable loads, and the supply impedance of the power system, as illustrated by Figure 2.1. Variable loads include loads such as crushers, arc furnaces and sawmills [10].

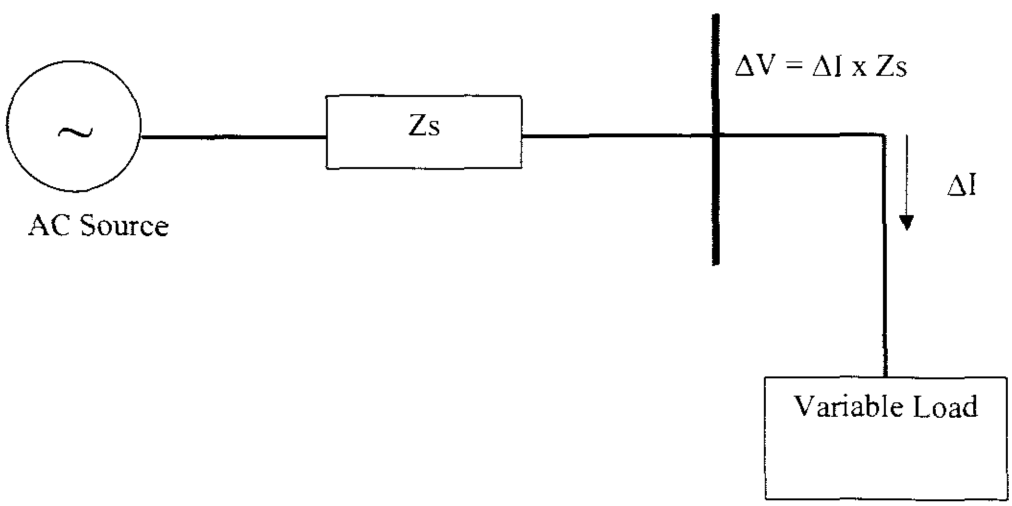

Figure 2-1 Voltage Fluctuation Caused by Variable Load

The fault level at the point of measurement, size of flicker producing load and the frequency at which the variation in voltage occurs determine the impact of the flicker levels emitted by the customers. The human eye is more sensitive and perceptible to flicker as a nuisance in comparison to effect of flicker in most electrical equipment [5]. The effects of flicker on equipment have been found to be insignificant, except in the cases of some television screen technologies (resulting in changes in the size of the image), and balancing technologies for fans and flywheels [10].

2.2 Flicker Evaluation and Measurements

Flicker measurement and evaluation are set out in the UIE (International Union of Electro-heat). Flicker is evaluated in terms of P_{st} (Short Term Flicker Severity Level). Two standardised sampling periods are normally used in a flicker meter where the first period, relating to P_{st} (Short Term Flicker Severity), is 10 minutes and the second period, relating the P_{lt} (Long Term Flicker Severity) is 2 hours. The 10 minute P_{st} sampling period is long enough to ensure that not much priority is given to isolated voltage changes due to dips or any system events. Furthermore it is long enough to allow a subject to notice the disturbance and its persistence, but at the same time it is short enough to allow detailed characterisation of a disturbing equipment with long lasting duty cycle [11].

The threshold at which flicker becomes perceptible to the human eye is at a P_{st} =1. This would mean that 50% of the people in a room would perceive the variation in luminance at a P_{st} =1. Figure 2.2 illustrates the perceptibility curves showing the sensitivity of the eye versus the frequency of the flicker [11].

The human eye reacts different on light flicker with respect to its frequency. The light-eye-brain chain is most sensitive for flickering light at a frequency of 8 – 10Hz. At the sawmill plants the frequency of the fluctuation in voltage corresponds to the sensitivity region of the eye. This is due to the operating frequency of the flywheels that rotate at frequencies of 5 – 10Hz [11]. This indicates that the operating frequencies of the Frame Saws falls within the critical band of the flicker perceptibility as can be seen from figure 2.2

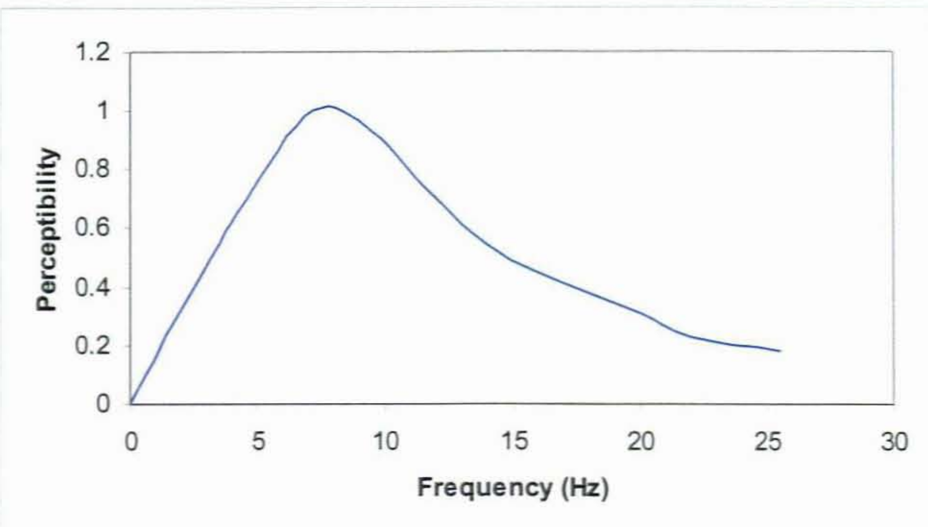

Figure 2-2 Perceptibility Curve for Visual Flicker

Flicker meters measure voltage fluctuations, analyse and filter the data, evaluate the data through a Gaussian distribution curve and scale the information accordingly. The resultant measurement value that is obtained represents the probability of a human perceiving flicker during the sample period where an output of one (P_{st} = 1) unit represents the threshold of flicker irritation. The flicker meter incorporates weighting curves that represent the response of the human eye to light variations produced in a 230V, 60W incandescent lamp. Measurements are carried out according to IEC 868 (International Electro-technical Commission) with a minimum period of one week [12].

During the measurement period the following considerations should be taken into account; network changes which results in significant changes in fault levels at the measure point, long term effects such as the temporary closure of some industries fed from a busbar [10].

The IEC 1000-3-7 standard [13] introduces the basis for determining the requirements for connecting large fluctuating loads to public power systems. The objective is to provide guidance for engineering practises which will ensure adequate service quality for all connected consumers.

When connecting a new customer to the public supply network, the utility needs to provide the customer with maximum allowable flicker emission levels which need to be reflected in the supply contract of the customer [5]. The compatibility levels are set out in the IEC 1000-3-7 as indicated in Table 2.1.

The compatibility levels are reference values for coordinating emission and immunity of equipment being part, or supplied by, a supply network in order to ensure the EMC (Electromagnetic Compatibility) in the whole system. These levels are applicable in LV and MV power systems where lighting technologies are applied [13]. The Eskom methods of measuring and evaluating flicker are based on IEC methods [10].

Flicker severity measure	Compatibility Levels
P_{st}	1.0
P_{lt}	0.8

Table 2-1 IEC Compatibility Levels for Flicker Severity

The NRS 048 sets minimum standards for the quality of the electrical product supplied by South African utilities to the end user [1]. The limits for flicker in the NRS 048 as indicated in Table 2.2, is similar to that of the IEC 1000-3-7 but also specify specifies a time frame for when maximum and minimum levels can occur.

	Compatibility Levels	
Flicker severity measure	Nominal daylight period 08:00 - 16:00	Nominal night period 16:00 – 08:00
P_{st}	1.25	1.0
P_{lt}	1.0	0.8

Table 2-2 NRS 048 Compatibility Levels for Flicker Severity

The maximum flicker severity of P_{st} = 1.25 during 08:00 to 16:00 is allowed due to the flicker perceptibility being less evident during the day than at night. For this reason the maximum flicker severity of P_{st} = 1 is allowed during 16:00 to 08:00 which is the time when flicker will be most perceptible to customers.

2.3 The "Cubic Summation Law"

When two loads are fed from the same supply and their flicker is measured individually, their total flicker can be calculated using the "Cubic Summation Law". The "Cubic Summation Law" is given by the formula (2.1);

$$\begin{aligned} P_{st}(\text{total}) &= \sqrt[3]{P_{st}(\text{load1})^3 + P_{st}(\text{load2})^3 + P_{st}(\text{load3})^3} \\ &= \sqrt[3]{P_{st}(\text{plant emission})} \end{aligned} \tag{2.1}$$

This formula is use predominantly where the risk of coincidence voltage occurring is small. Load 1, load 2 and the n^{th} load refer to the individual load which can be summated to get the total flicker emission [13].

When the total flicker measurements are completed, the contribution of the sawmill plant to the total flicker measured can be calculated using the "Cubic Summation Law". This law is used to subtract the background flicker from the total flicker level measured by the flicker meter. The background flicker refers to the flicker level present on the 400V busbar when the sawmill plant is not in operation. This flicker level is representative of the flicker level present on the supply network. The background flicker level on the power system is important parameter to be taken into account when ascertaining the flicker emission of the sawmill plant only [14].

The total flicker measured is therefore equal to the summation of the background flicker and the sawmill plant flicker levels. Equation (2.1) can therefore be expanded to;

$$P_{st}(\text{total}) = \sqrt[3]{P_{st}(\text{plant emission})^3 + P_{st}(\text{background})^3} \tag{2.2}$$

This Cubic Summation Law can be used to calculate the contribution of the sawmill plant to the total flicker level, therefore equation 2.2 can be re-arrange as;

$$P_{st}(\text{plant emission}) = \sqrt[3]{P_{st}(\text{total})^3 - P_{st}(\text{back ground})^3} \tag{2.3}$$

2.4 Flicker Prediction

Standard flicker curves are available in IEC 1000-3-7. This curve indicates the voltage fluctuations and the frequencies with reference to the 230V, 60W incandescent lamp as indicated in Figure 2.3. This curve can be used to determine the flicker emitted by cyclic loads, which have a consistent voltage fluctuation at a specific frequency. The curve indicates the voltage compatibility levels for voltage changes [13].

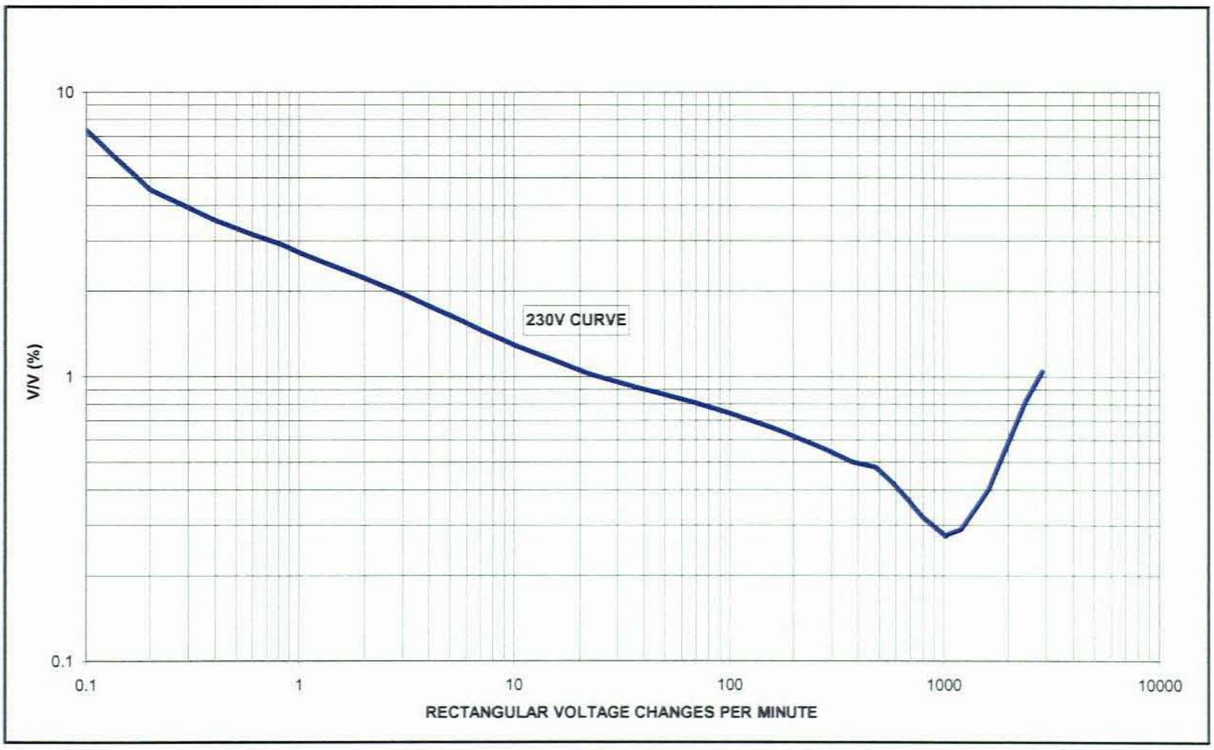

Figure 2-3 P_{st}= 1 Curve for Rectangular Voltage Change

Due to varying loads of non-cyclic nature, the associated flicker levels cannot be predicted using these standard curves. This is due to the random voltage fluctuation caused by the variable load such arc furnaces, crusher plants and sawmills.

Flicker is playing an increasing role in the design an operation of electric arc furnace plants. This is because arc furnaces produce significant amounts of flicker and are critical loads as far as flicker emission is concerned. An arc furnace uses electric arcs to convert electrical energy to heat energy. An open-arc scrap-melting furnace produces load variations between the extremes of a brief full short circuit to an open circuit within milliseconds to cause a high flicker emission level from the arc furnace [3]. Deviations in the arc are greatest during the initial melting period due to random movement of the material in the ladle. The voltage drop of the arc depends on the type of material as well as the random movement of the electrodes [4].

The empirical formula was introduced to predict the flicker levels on non-cyclic loads such as arc furnaces and crusher plants.
A comparative analysis between the predicted and the measured flicker levels for the crusher plants reveals a maximum percentage error of 6.84%. This percentage error can be attributed largely to the variation in mechanical settings of crushers [7].

Sawmill loads are similar to arc furnaces and crusher plants in terms of the variable loads. These loads are all non-cyclic loads therefore the flicker curves cannot be used to predict their flicker. The approach of predicting the sawmill loads flicker emission using the empirical formula therefore seems justified.

2.5 Problem Statement

In 1996 the National Electricity Regulator in South Africa published a document, the NRS 048 standard. This document dictates compatibility levels for power quality disturbances which utilities must adhere to when supplying power to consumers. A lot of research has been done on flicker producing loads such as arc furnaces and rock crusher to ensure flicker limits will not be exceeded on the network. The research has led to the development of an empirical formula to predict the flicker before the customer is connected to the network [2,3,4,6,7].

At present no conclusive procedures exist to predict the flicker emission of sawmills on the network. The objective of this thesis is to determine the accuracy of the K_{sm} factor for Frame Saws. The utilities' planning department will therefore be able to use these K_{sm} factors together with the empirical formula to predict the flicker emission of future sawmill plants. Due to the cost involved to both utility and customer to rectify quality of supply problems, this technique will ensure compliance to the specified limits before the load is connected to the network.

Previous research [15] has shown that the Circular and Multi-rip Saw have a negligible effect on the flicker. This is due their blade speed being very close to the motor speed therefore, the frequencies at which the blades rotate are approximately 50Hz. At this frequency flicker would not be a problem to the human eye as it falls outside the perceptibility region as indicated in Figure 2.2 [15]. The operating frequency of the Frame Saws is between 5 – 10Hz. At these frequencies the human eye is more sensitive to flicker. For this reason the main focus of this thesis is on the accuracy of the K_{sm} factors for Frame Saws. For completion of the thesis document mention is also made of the K_{sm} factors for the Circular and Multi-rip Saws as these saws are commonly used at various sawmill.

2.6 The Need for Predicting Flicker

As more is needed to be known about flicker and Frame Saws this topic is investigated in this thesis. For the reasons describe Frame Saws are loads that predominantly effect the flicker level at sawmill plants. In a preliminary investigation [15] K_{sm} factors at a site were found to be different although their mechanical operation were similar. The inconsistency in the K_{sm} factors has led to this research in determining the impact of the mechanical variables of the saw and the hardness and density of the wood.

2.7 Sawmill Loads

Different types of saws namely the Circular, Multi-rip and Frames Saws are being used at a sawmill plant. These saws are used in either the primary or secondary cutting process. A brief description of the various saws and their operation is described.

2.8 Mechanical Description of the Frame Saws

The Frame Saw is used for sawing logs of up to 530mm in diameter with a maximum length of 6.3m. A 380V, 3-phase AC motor drives the saw. The motor sizes ranges from 90 to 132kW per machine which drives two flywheels by the use of vee-belts.
The blades of the saw are installed in a frame, which in turn is connected to the flywheels by a crankshaft. The flywheel diameter (Ø) varies from saw to saw [15].

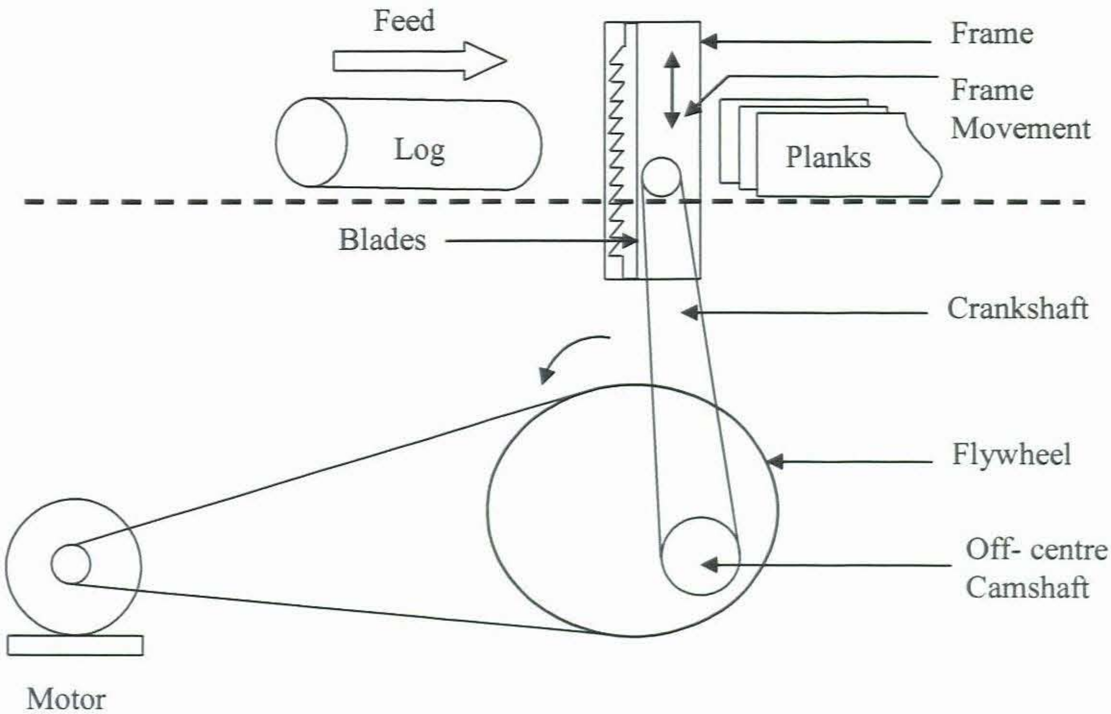

Figure 2-4 Sawing Process of the Frame Saws

During the cutting stage i.e. the downstroke, the motor speed decreases and causes the motor to decelerate. With the upstroke the blades do not cut the logs. During this stage the motor speed increases. The operation of this saw is illustrated in Figure 2.4. The variation in motor speed (Δn) causes a variation in the load current (ΔI) drawn by the motor and is shown in Figure 2.5. This leads to fluctuation in the voltage (ΔV) [15].

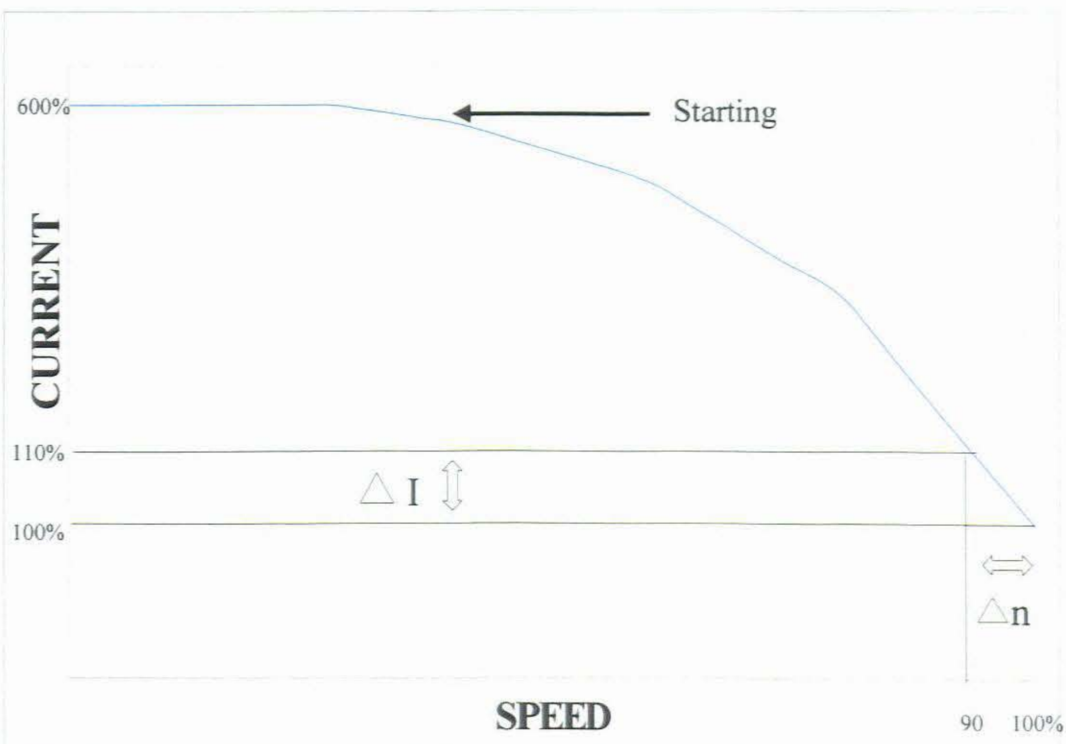

Figure 2-5 Motor Current vs. Speed Graph

Half of the flywheel acts as a counter weight on the Frame Saws as shown in Figure 2.6. When the Frame Saw is at rest, the sash (frame) where the blades are installed is at its highest position and the counter weight is at the bottom. When the saw is in operation the motor draws more current and consequently a higher output to get the counter weight to the top. During this process the logs are not being cut. On the down swing of the counter weight the log is being cut. Once the flywheels are in motion the counter weights help mechanically with the cutting process.

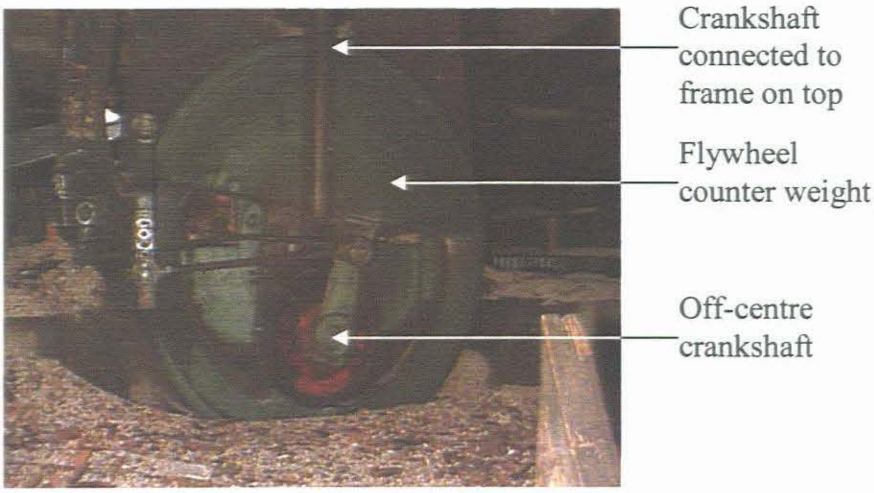

Figure 2-6 Flywheel Counter Weight

To control this process the flywheels needs to run at a speed specified for the certain type of saw. This speed varies for the different types of machines from 310 to 360 rpm (revolutions per minute) per machine. This speed together with the diameter of log determines the production rate.

The number of pole pairs for the 380V, 3-phase AC motors being used to drive the flywheels of the Frame Saws range from 4 to 8 poles per motor. This translates to a motor speed range from 1440 rpm to 733 rpm respectively. The formula [19] to determine the motor speed is expressed as:

$$n = \frac{f}{p} \qquad (2.4)$$

Where,
n = the motor speed in revolutions per second
p = the number of pole pairs
f = the frequency in Hz

To determine the speed in revolutions per minute the formula becomes;

$$n = \frac{f \times 60}{p} \qquad (2.5)$$

Therefore, a 4 pole motor will have 2 pole pairs and the synchronous speed will be calculated using equation 2.5 as follows:

$$n = \frac{50 \times 60}{2}$$
$$= 1500\text{rpm}$$

Intermediate pulleys are being used in order to change the flywheel speed to the optimal speed. The Frame Saw production line consists normally of two Frame Saws in series.

Frame Saw 1

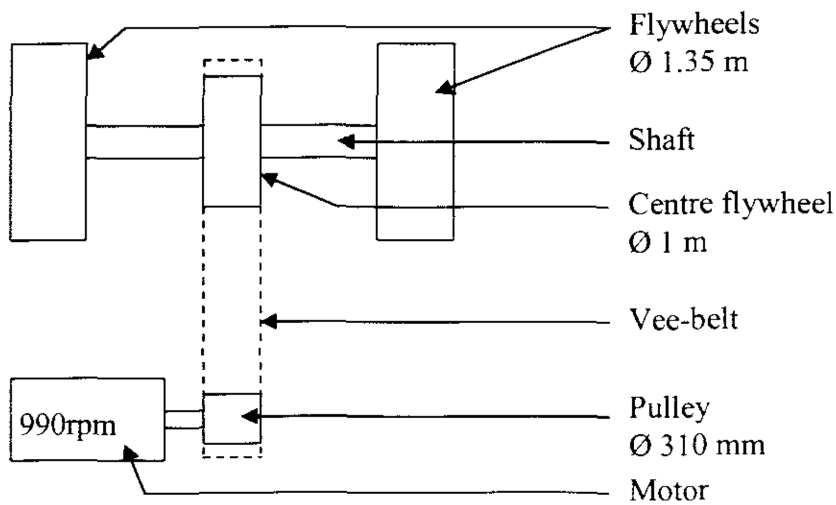

Figure 2-7 Frame Saw 1 Mechanical Flywheel Configuration

The speed of the flywheels for Frame Saw 1 is normally slower than Frame Saw 2. This is to prevent accumulation of logs to Frame Saw 2. A typical speed for the two saws is 306 rpm (Frame Saw 1) and 328 rpm (Frame Saw 2) respectively. The configuration of the pulleys to obtain these speeds depends on the motor specifications. Typical configurations for Frame Saw 1 and 2 are illustrated in Figure 2.7 and 2.8.
A typical mechanical configuration for Frame Saw 1 is indicated in Figure 2.7. With the given flywheels, pulley diameter and motor speed, the speed at which the flywheel will run can be calculated as follows [20]:

$$D_1 N_1 = D_2 N_2 \qquad (2.6)$$

where,

D_1 = driving motor pulley in mm
N_1 = motor speed in rpm
D_2 = driven pulley of flywheels in mm
N_2 = flywheel speed in rpm

From equation 2.6 with application to Frame Saws to determine the flywheel speed it can be rewritten as;

$$\text{flywheel speed (rpm)} = \frac{\text{driver motor pulley (mm)}}{\text{driven flywheel pulley (mm)}} \times \text{motor speed (rpm)} \qquad (2.7)$$

Frame Saw 1 flywheel speed and frequency can now be determined using equation (2.7) and (2.5) respectively.

$$\text{flywheel speed} = \frac{310}{1000} \times 990$$

$$= 306 \text{ rpm}$$

Therefore,

$$f = \frac{1}{p}$$

where,

f = frequency

p = period

$$f = \frac{306}{60}$$

$$= 5.1 \text{ Hz}$$

The speed of the flywheel was verified with a tachometer. With this speed, the saw blade speed of Frame Saw 1 is running at a frequency of 5.1Hz. At this frequency the flicker could lead to visual discomfort to the human eye as shown in the flicker perceptibility curve in Figure 2.2, Chapter 2.

Frame Saw 2

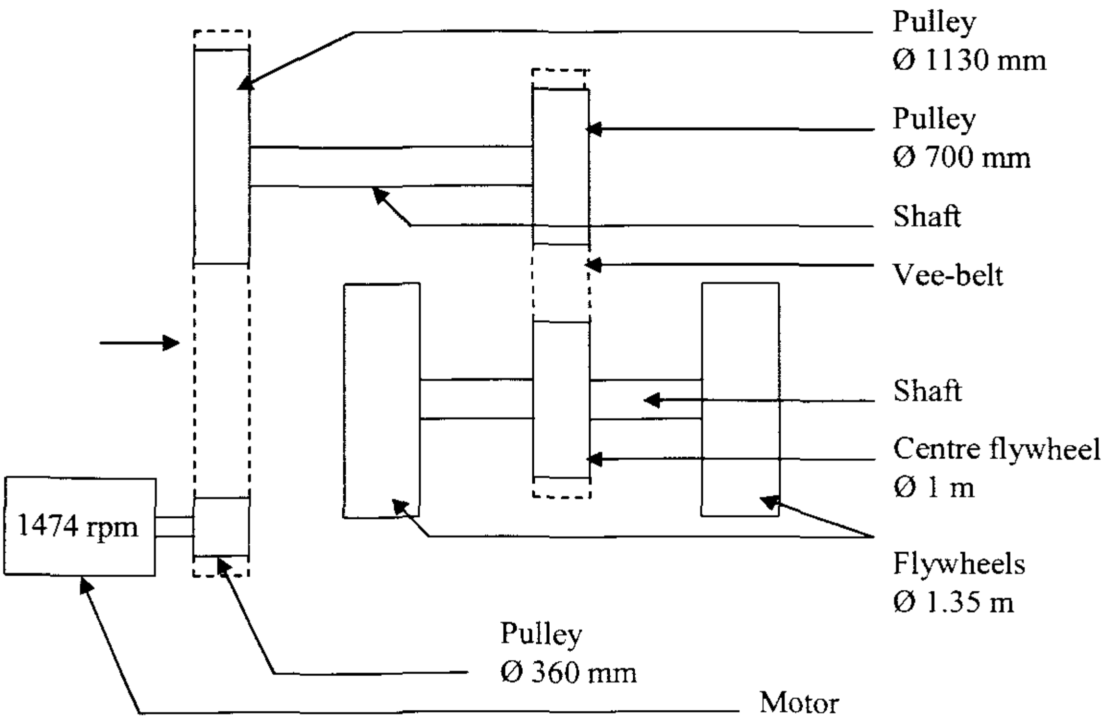

Figure 2-8 Frame Saw 2 Mechanical Flywheel Configuration

Using formula (2.7) and (2.5) the speed of the flywheel and frequency for Frame Saw 2 can be calculated as follows:

$$\text{flywheel speed} = \frac{360}{1130} \times \frac{700}{1000} \times 1474$$

$$= 328 \text{ rpm}$$

Therefore,

$$f = \frac{1}{p}$$

where,

f = frequency

p = period

$$f = \frac{328}{60}$$

$$= 5.4\text{Hz}$$

This speed was verified with a tachometer. With this speed the saw blade speed of Frame Saw 2 is 5.4Hz. This frequency also falls within the sensitive region according to Figure 2.2 where the flicker could cause visual discomfort to the human eye according the to perceptibility curve shown in Figure 2.2, Chapter 2.

2.9 Production Process of the Frame Saws

The Frame Saw production line consists of two Frame Saws in series as shown in Figure 2.9. The operation of the two Frame Saws is similar. However their mechanical configuration is different due to the cutting process.

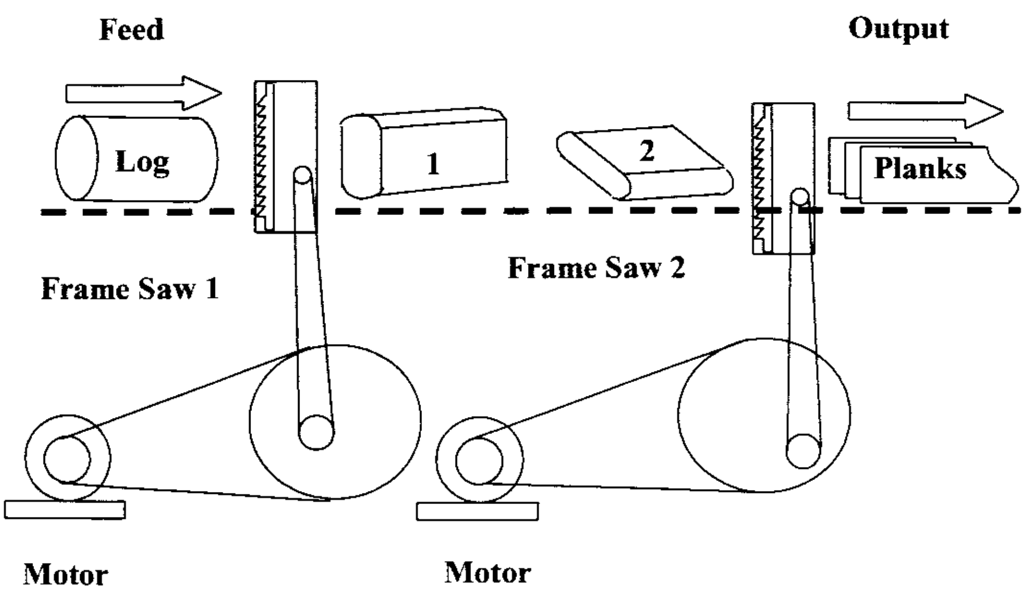

Figure 2-9 Production Process of the Frame Saws

The first Frame Saw does the primary sawing which involves the raw logs being cut to remove the bark.

The result of the primary cutting process is indicated as log number 1 in Figure 2.9. Frame Saw two is used for the secondary sawing which involves the cutting of the rest of the logs, where log number 1 is flipped around, shown as number 2 in Figure 2.9.
Log number 2 is then cut into smaller pieces that makes up the final product, which are planks, as shown in Figure 2.9 [15].

2.10 Mechanical Description of the Circular Saw

The Circular Saw is driven by a 40kW motor and is used for cutting logs of diameters of up to 250mm with a maximum length of 4.8m. This (380V, 3-phase AC) motor drives the blades of the Circular Saw by use of vee-belts. The blades are connected to a camshaft. The operation of this saw is illustrated in Figure 2.10 [15]. Due to the blades being directly mechanically connected to the motor, the speed of the blades would be very close to the motor speed therefore, the frequency at which the blades rotate are approximately 50Hz.

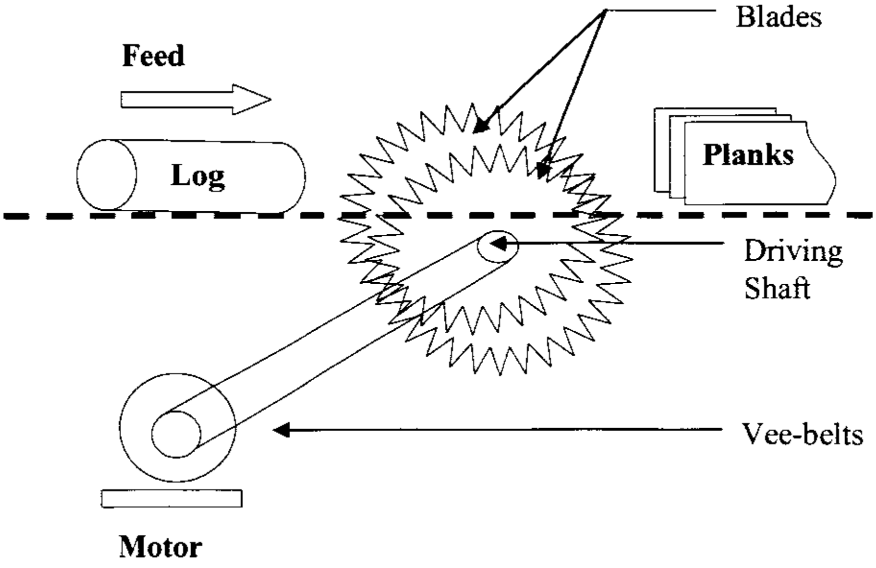

Figure 2-10 Operation of the Circular Saw

2.11 Mechanical Description of the Multi-rip Saw

The Multi-rip Saw also commonly known as the board edger is driven by a 220kW, 380V, 3-phase AC motor. This motor drives the blades of the Multi-rip by use of vee-belts. The blades are connected to a camshaft. The number of blades for this machine varies according to production requirements. The operation of this saw is illustrated in Figure 2.11 [15]. This motor is also directly connected to the blades. The blades speed would therefore at the motor rated speed. The frequency of this speed would be approximately 50Hz.

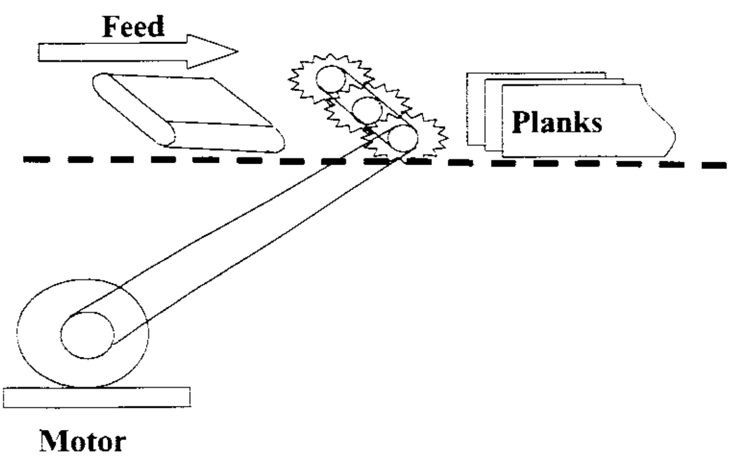

Figure 2-11 Operation of the Multi-rip Saw

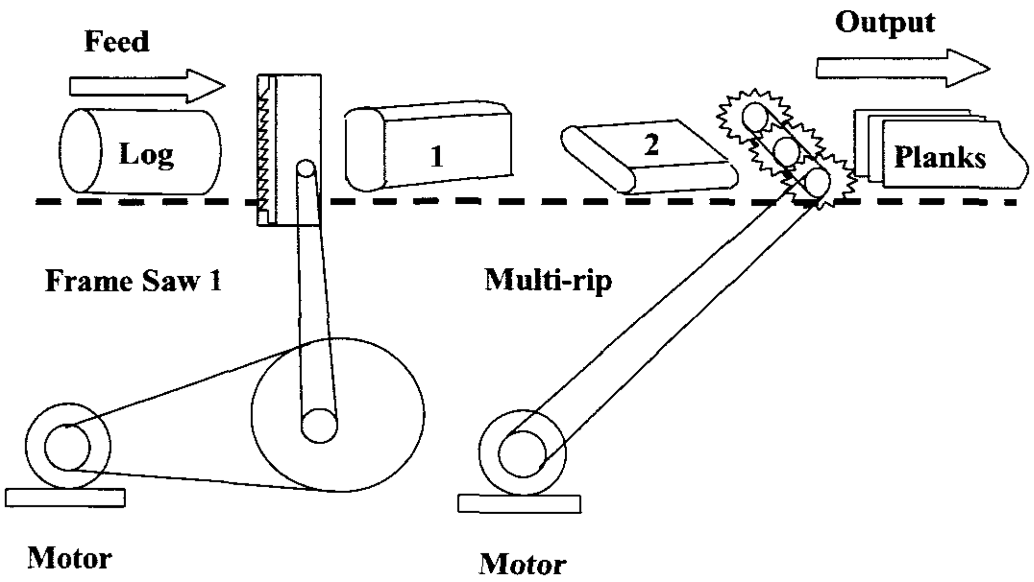

Figure 2-13 Production Process of Frame Saw 1 and Multi-rip Saw

2.13 Calculated K_{sm} Factors for Circular and Multi-rip Saw

Previous research has indicated that the Circular and Multi-rip saw does not impact on the systems flicker level [9]. This is due to the high frequency 50Hz, which they operate at. The K_{sm} factors for the Circular and Multi-rip Saw are tabulated in Table 2.3 [9]. The K_{sm} of 88 for the Circular Saw was high due to an undersized motor being used for the application and consequently would have given rise to a high K_{sm} factor being calculated.

Type of load	K_{sm}
Circular Saw	88
Multi-rip Saw	19

Table 2-3 Calculated K_{sm} Factors for Circular and Multi-rip Saw

The human eye is most sensitive to the variation in luminance in the region of 8-10Hz, for this reason if the blades rotate at approximately 50Hz the human eye will not be able to perceive the variation. At this operating frequency flicker would not be a problem to the human eye as shown in the flicker perceptibility curve in Figure 2.2, Chapter 2. The flicker contribution of these saws needs to be analysed in order to calculate its contribution to the total plant emission.

2.14 Calculated K_{sm} Factors for Frame Saws

The Frame Saws are loads that predominantly effect the flicker level at the sawmill plants.

Type of load	K_{sm}
Frame Saw 1	51
Frame Saw 2	40

Table 2-4 Calculated K_{sm} Factors for Frame Saws

The calculated K_{sm} factors for the Frame Saws are tabulated in Table 2.4 [9]. From table 2.4, the K_{sm} factors for Frame Saws 1 and 2 were found to be different although their mechanical operation are similar. The reason for the inconsistency in the Ksm factors has led to this research. As the mechanical is similar, other reasons why the K_{sm} factors are different, needed investigation and this led to the possibility that the mechanical properties of timbers could be one of the main causes.

2.15 Mechanical Properties of Timbers

Plantation trees are defined as either hardwood or softwood. The hardwoods are Eucalyptus and Wattles. The Pine species are all categorised as softwoods. The Pine species is not indigenous to South Africa. South Africa has a plantation area of 1 486 923 hectares representing 1.2% of the land area. Figure 2.14 indicates the forestry areas of South Africa. Plantation area by province; Mpumalanga 41%, Kwazulu – Natal 38%, Eastern Cape 11%, Northern Province 4.2% and Western Cape 5.6%. The remaining provinces have negligible plantation areas due to mainly climatic restraints.

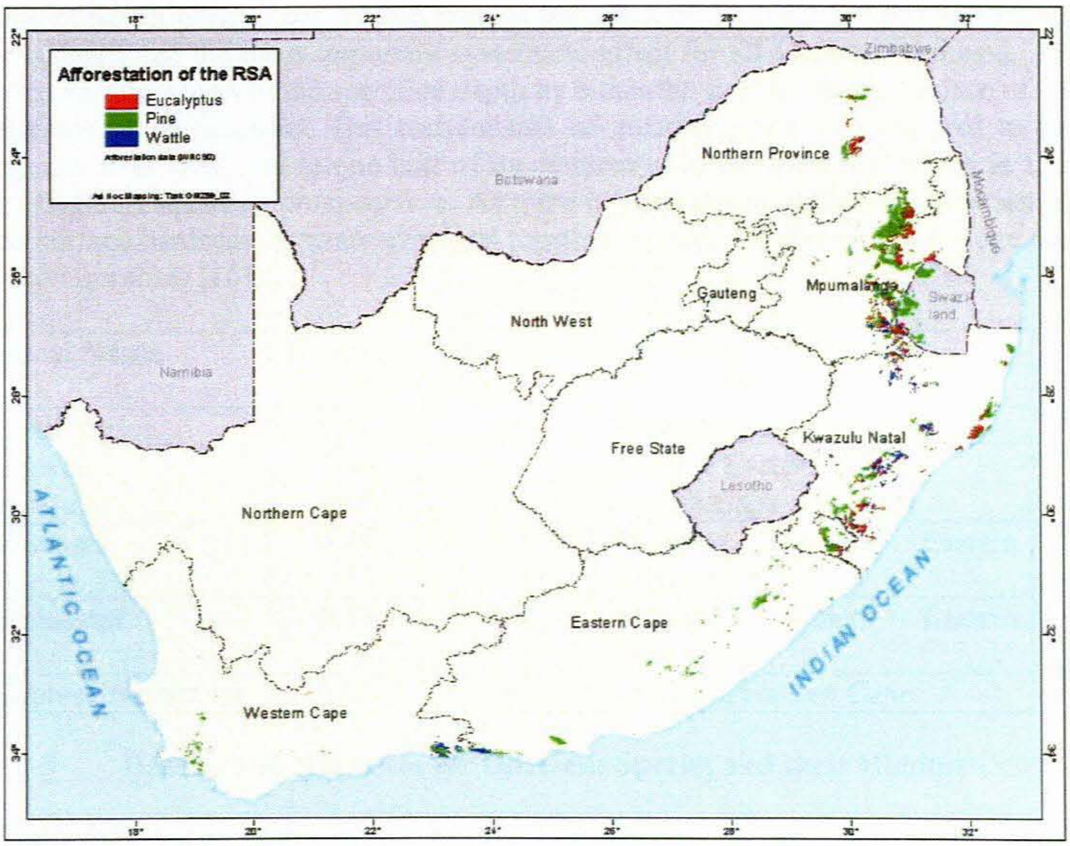

Figure 2-14 Forestry Areas of South Africa

The density of the wood is the ratio of the weight of a substance to that of an equal volume of water. Since the measure of density is expressed in terms of grams per cubic centimetre (g/cm^3) it may for all practical purposes be considered as being Specific Gravity [16].Specific gravity affords a much better index to the strength (density) of the individual pieces within a particular species than to the average strength for different species.

The strength (density) at any particular specific gravity can be calculated with the following equation:

$$\frac{S}{S_1} = \left(\frac{G}{G_1}\right)^n \qquad (2.8)$$

Where,
S = strength corresponding to specific gravity, G
S_1 = strength corresponding to specific gravity G_1
n = exponent values for variation in strength properties within a particular species

There is not only a considerable variation in the density of wood of a single species but even in a single stem [16]. This variation may be due to the age of the tree, the position in the stem from which wood is taken, various environmental factors associated with growth, the arrangement of individual cells or the physiochemical composition of the cell walls. All these mechanical properties of the timbers are of particularly reference to those grown in the Republic of South Africa [16]. Within species the effect of the height of the tree and number of rings constituted the most important systematic effect for all features examined [17]. The resistance to indentation to the specified depth by either the side or the end surface of a timber is a measure of its hardness. This test consists of measuring the load required to imbed a 11.2mm diameter steel ball to one half of its diameter into the specimen which is 152.4mm long by 50.8mm square in cross-section. As there is generally no difference between the side and end surface hardness, they are averaged together as "side hardness" to have one value for calculation purposes [16].

Botanical Name	Density (g/cm^3)	Hardness (kN)	Province
Pinus elliottii	0.44	2.9	Southern, Eastern Cape
Pinus teada	0.44	2.6	South & Eastern Cape
Pinus patula	0.45	2.7	Eastern Cape
Pinus radiata	0.48	3.2	Western, Southern, Eastern Cape
Pinus pinaster	0.53	4.4	Western, Southern, Eastern Cape
Eucalyptus diversicolor	0.79	8	Southern, Eastern Cape

Table 2-5 Density and Hardness for Different Species and their Habitat

Significant differences in the flicker levels could possibly be attributed to the density and hardness of the wood being cut. The density and hardness figures indicated in Table 2.5 are the average values for each specie. The botanical name for the Pine trees is called the Pinus. The types of Pine trees indicated in Table 2.5 are the various types, which are predominantly found in South Africa. Within this specie the higher density Pine trees are commonly found in the Southern and Eastern Cape Province [18]. From the table it is evident that the density and hardness of the various types of wood differ from each other. The Eucalyptus diversicolor also known as the Karri has got a greater density and hardness than that of Pine.

2.16 Summary

In this chapter the concept of flicker was discussed outlining the definition of flicker. The factors affecting the flicker levels are described. The evaluation and the effects were illustrated. Theoretically the severity of flicker depends on the voltage fluctuation and the frequency at which the voltage changes occur.

These frequency changes are most perceptible to the human eye in the 8 – 10Hz range. Sawmill loads are non – cyclic in nature, for this reason the standard curves set out in the IEC 1000-3-7 for predicting flicker cannot be used. The prediction technique will enable the utilities' planning department to ensure that the flicker levels will not be exceeded on the network. The empirical formula was used to calculate the K_{sm} factors for the sawmill loads. This technique was proven to be very effective on the crusher plants and was therefore suitable for sawmill plants.
The accuracy of the K_{sm} formula on sawmill loads needs to be confirmed in order to be applied by utilities.

The mechanical operation of the various saws present at the sawmills was described. The speed at which the flywheels of the Frame Saws rotate depends on the mechanical configuration and their motor size. Typical speed of the flywheels range from 310 to 360 rpm. With this operating speed the saw blades frequency is about 5Hz. This is the speed at which the blades cut the logs. This is according to the specifications set out in the manual for these machines. At this operating frequency of 5Hz, flicker can lead to visual discomfort to the human eye according to the perceptibility curve.

The counter weight on the flywheel acts as a mechanism to control the momentum of the Frame Saw. The production process of the Frames Saws commonly involves two Frame Saws in series. Frame Saw one does the primary cutting and Frame Saw two is used for the secondary sawing.

The second possible production line consists of a Circular and Multi-rip Saw. These saw blades run at frequencies of 50Hz. At this operating frequency these saws would not cause problems to the human eye which is most sensitive to flicker in the region of 8 – 10Hz. The Circular Saw does the primary sawing and the Multi-rip the secondary sawing. The Multi-rip is yet another set-up commonly used with a Frame Saw in a production line. When it is used with a Frame Saw it still does the secondary sawing. Although the Circular and Multi-rip have a negligible effect on the flicker emission due to its operating frequencies K_{sm} factors was still calculated in order to determine it's the total flicker emission contribution of the sawmill plant.

The different types of wood together with their density and hardness could lead to different flicker levels being measured. For this reason, the mechanical properties of timbers and their geographical locations in South Africa are introduced.

Chapter 3

3 Developed Methodology

This chapter describes the methodology developed to predict the flicker levels on sawmill plants. Practical examples are used to illustrate how the developed methodology as a tool for predicting flicker emission at sawmills is applied.

3.1 General Methodology

The flow chart in Figure 3.1 illustrates the proposed methodology which involves five steps to be applied at sawmills.

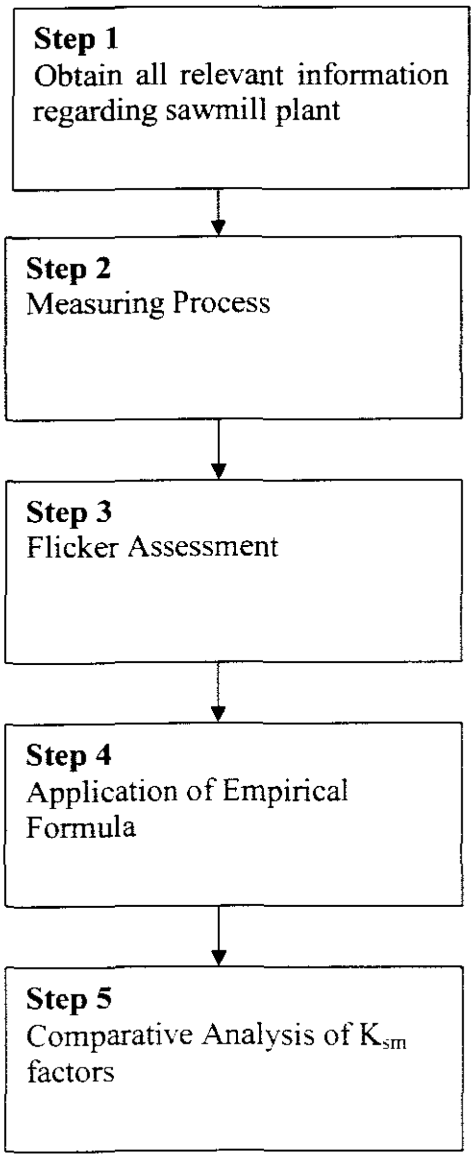

Figure 3-1 Flow chart of Methodology

Step 1: Obtain all relevant information regarding sawmill plant

All relevant information regarding the sawmill needs to be obtained before the actual measurements can take place. This information includes;

- A electrical single line diagram layout to ensure that instrumentation will be installed at the correct loads. If a single line diagram is not available the relevant cables needs to be traced.
- Transformer specification information needs to be taken for proper calculation purposes.
- The three phase fault levels on the 11kV busbar needs to be obtained from the utility.
- The motor specifications for the use of empirical formula and to determine the speed, and frequency of flywheels.
- The Frame Saws flywheel diameter sizes, number of blades, pulleys, intermediate pulley sizes and what type of mechanical configuration is used.
- The geographical area and location area from where the wood is sourced which will determine the type of wood being cut.

All this information is needed to ensure that the instrumentation is installed at the correct place and that accurate calculations can be performed.

Step 2: Measuring Process

The flicker meter (FM) and voltage recorder (VR) is connected on the secondary side of the transformer as shown in Figure 3.2. The voltage recorder is used to measure the voltage and dip data which is critical to ensure that the assessed flicker levels are not affected by voltage dips on the supply network. This connection method is used at all sawmills to ensure consistency in terms of measurements done.

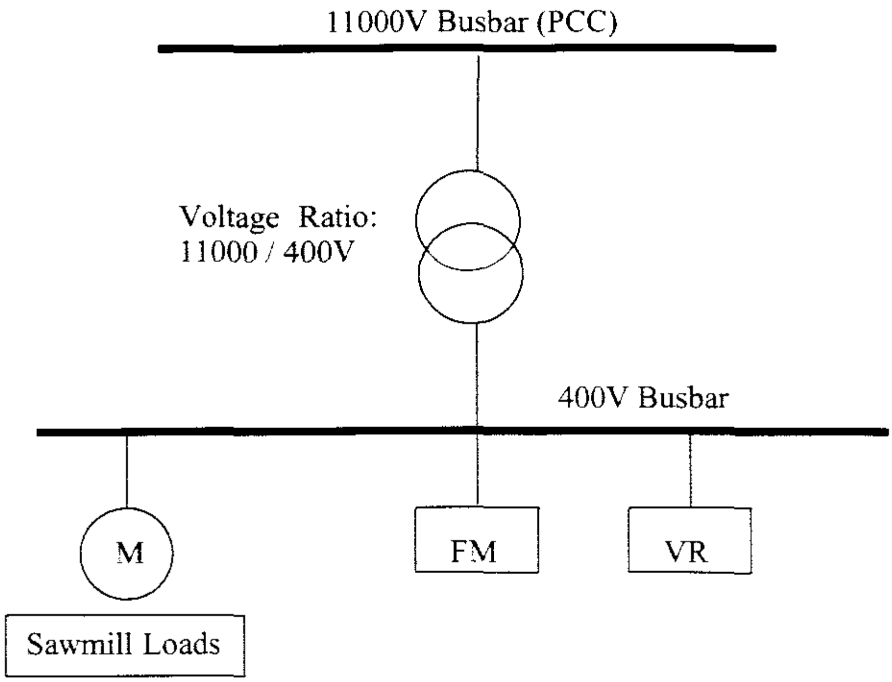

Figure 3-2 Typical Single Line Diagram of Sawmill

A production line consists normally of two Frame Saws in series. Total flicker measurements are done when both these saws are in operation. When a sawmill plant consists of two Frame Saws, individual flicker measurements need to done. This is difficult to achieve during normal operation as it affects the production output. However it can be done during production breaks when the plant is inoperative, which is normally an hour for most plants.

The flicker meter records 10 minute P_{st} values. This implies that after every change in the production process a new value will only be seen 10 minute after the change. This change can be a stop or start of a saw. Just before the production break (lunch) while both Frame Saws are running the operators should leave Frame Saw 1 running. At lunch time Frame Saw 2 must be stopped while Frame Saw 1 is still running. Frame Saw 1 should run for at least half an hour to get a P_{st} value for this Frame Saw. After a value is obtained for Frame Saw 1 it can be stopped. Frame Saw 2 can now be switched on. After 10 minutes the start effect for Frame 2 would have passed. The next 10 minutes, while the saw is running will give a P_{st} value for Frame Saw 2. During the measurement process, notes are made known, as the log sheet when the saws were switched on or off and for how long.

Step 3: Flicker Assessment

Once all measurements have been completed the assessment can be done. This step involves the interpretation of the data and graphs see appendix A. As the program used is DOS-based (Disk Operated System) the data is converted into an excel spreadsheet and the graphs are done in a spreadsheet. The log sheets are now being used to check the P_{st} values when the saws were switched on and when it was in operation. If any unusual high flicker values are present the voltage recorder data will be used to check if this was not due to a supply system event. The assessed flicker levels will now be determined from the measured data.

Step 4: Application of Empirical Formula

Before the empirical formula can be applied, fault calculations at the measuring point needs to be done. The three phase fault level on the 11kV busbar is normally available from the utility. However, measurements are done on the supply busbar to the sawmill plant therefore the fault calculations need to be done at that point of measurement see appendix B. Using the empirical formula a K_{sm} factor can now be determined for the saws.

Step 5: Comparative Analysis K_{sm} factors

All calculated K_{sm} factors are compared to determine if the accuracy of the K_{sm} factors is correct or not.

3.2 Application of Methodology

Practical examples are used to illustrate the use of the developed prediction technique.

In order to calculate the K_{sm} factors of the various saws at the sawmill plants, the sawmill flicker levels needs to be measured. Once the flicker levels have been assessed and the motor size and fault levels have determined the K_{sm} factors can be calculated. At certain plants each saw flicker levels were measured individually during production breaks when the plant was inoperative.

The application of the empirical formula is illustrated in the following example:

A sawmill plant consists of two Frame Saws operating in series. Each Frame Saw is driven by a 132kW motor. The measured flicker level for Frame Saw 1 is $P_{st} = 0.97$ and Frame Saw 2 $P_{st} = 0.75$. The fault level on the 400V busbar is 7.05 MVA.

The K_{sm} factors for Frame Saw 1 and 2 can be calculated using the empirical formula, equation (1.1);

$$P_{st} = \frac{K_{sm} \times \text{Load size}}{\text{Fault level}}$$

Therefore,

K_{sm} for Frame Saw 1

$$K_{sm} = \frac{P_{st} \text{ x Fault level}}{\text{Load size}}$$

$$= \frac{0.97 \text{ x } 7050000}{132000}$$

$$= 51$$

$$P_{st} = \frac{K_{sm} \times \text{Load size}}{\text{Fault level}}$$

Therefore,

K_{sm} for Frame Saw 2

$$K_{sm} = \frac{P_{st} \text{ x Fault Level}}{\text{Load size}}$$

$$= \frac{0.75 \text{ x } 7050000}{132000}$$

$$= 40$$

3.3 Summating of Flicker Levels

Two Frame Saws operate in series where the output logs of the first saw is the input to the second saw as illustrated in Figure 2.9 page 14. One saw was operated at a time during lunch hours to measure the flicker level of the specific saw. The measured flicker level for Frame Saw 1 was $P_{st} = 0.97$ and Frame Saw 2 $P_{st} = 0.75$. To verify the total flicker that was measured, the "Cubic Summation Law" can be used (See Chap.2, Equation 2.1).

The application of the "Cubic Summation Law" is illustrated in the following examples:

$$P_{st}(\text{total}) = \sqrt[3]{P_{st}(\text{load1})^3 + P_{st}(\text{load2})^3 + P_{st}(\text{load3})^3}$$
$$= \sqrt[3]{P_{st}(\text{plant emission})}$$

$$P_{st}(\text{total}) = \sqrt[3]{(0.97)^3 + (0.75)^3}$$
$$P_{st}(\text{total}) = 1.10$$

The total flicker measured with the flicker meter on the customers 400V busbar is equal to P_{st} = 2. This value was measured during normal operation of the sawmill plant. The background flicker was measured to be Pst = 0.3 when the plant was inoperative.

The "Cubic Summation Law" can now be used to calculate the contribution of the sawmill plant to the total flicker level (See Chap.2, Equation 2.3).

$$P_{st}(\text{plant emission}) = \sqrt[3]{P_{st}(\text{total})^3 - P_{st}(\text{back ground})^3}$$

Therfore,

$$P_{st}(\text{plant emission}) = \sqrt[3]{(2)^3 - (0.3)^3}$$
$$P_{st}(\text{plant emission}) \cong 2$$

The total flicker contribution from the sawmill plant would therefore be approximately P_{st} = 2.

3.4 Summary

The application of the empirical formula was illustrated with the use of an example. The use of the "Cubic Summation law" to calculate the total or individual flicker emitted was also illustrated with a example. An overview of the use of the application of prediction technique was illustrated with the use of practical examples.

The following methodology was developed in order to determine the accuracy of the K_{sm} factors:

1. Install and measuring the flicker levels at sawmill plants.
2. Calculate the fault levels at the 400V busbar which is the point of measurement.
3. Analyse the measured flicker levels.
4. With the use of the empirical formula calculate the K_{sm} factors for the different saws.
5. Compare the accuracy of the K_{sm} factors to the previously calculated values determined at other sawmills.

Chapter 4

4 Case Studies

The objective of this chapter is to illustrate the application of the methodology with the use of practical examples by means of case studies.

4.1 Geographical Location of Sawmill Plants Investigated

The location of the sawmill plants investigated is shown in Figure 4.1. A total of 45 formal Sawmill plants are distributed across South Africa. This industry has got a net margin of approximately R77.7million per annum. A total of 9 sawmill plants was investigated in the Western and Eastern Cape Province. Within the Pine (soft wood) specie the higher density and harder type Pine trees are commonly found in the Southern and Eastern Cape regions in South Africa [18].

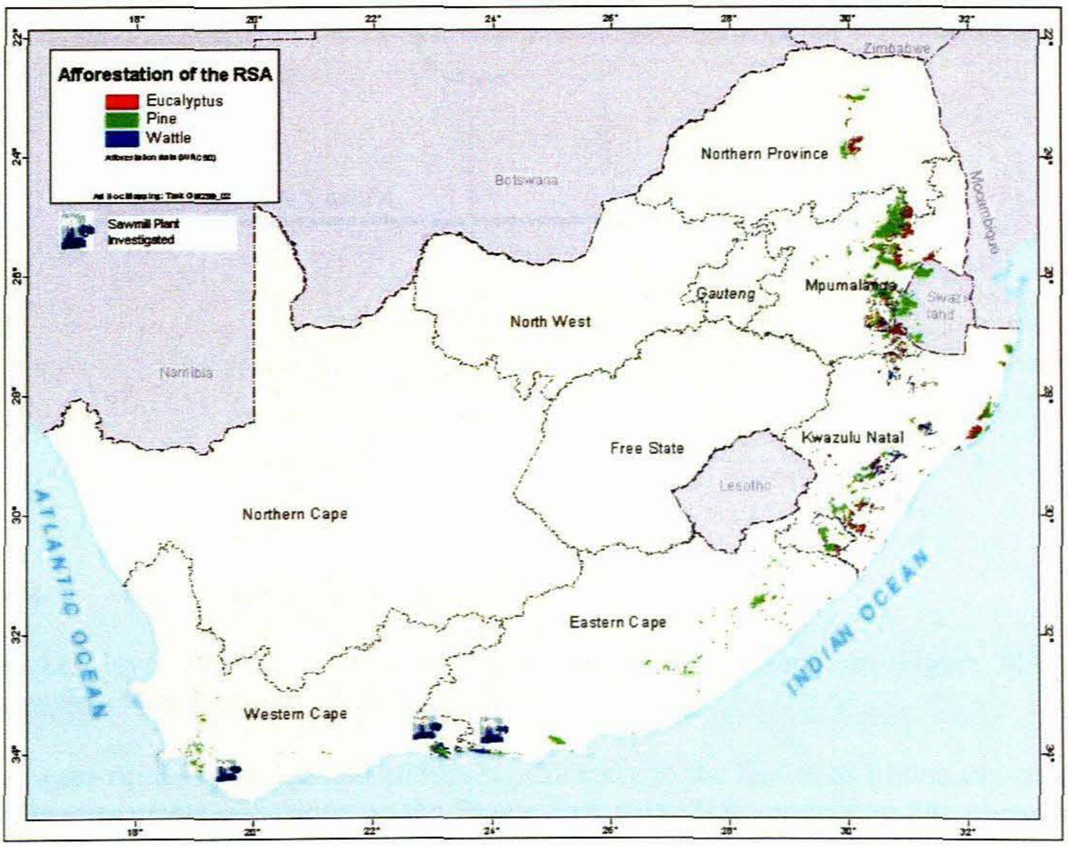

Figure 4-1 Sawmill Plants Investigated

4.2 Case Study 1 – Sawmill A

In order to predict the flicker emitted by the Frame Saws, measurements were performed at various sawmill plants to determine the flicker levels of these saws [8].

The flicker meter was connected on the 400V busbar at the majority of the sawmills to ensure consistency in terms of the measurements done. The electrical layout for Sawmill A is shown in Figure 4.2. This sawmill is located in the Western Cape region where the softer type of Pine trees are found.

The flicker meter (FM) and the voltage recorder (VR) were connected to the 400V secondary side of the transformer. The total flicker emission was measured on the 400V busbar. Sawmill A consisted of a Frame Saw only and a Multi–rip Saw to complete the production process. This process is discussed in Figure 2.13, Chapter 2. The Frame Saw is driven by a 90kW motor.

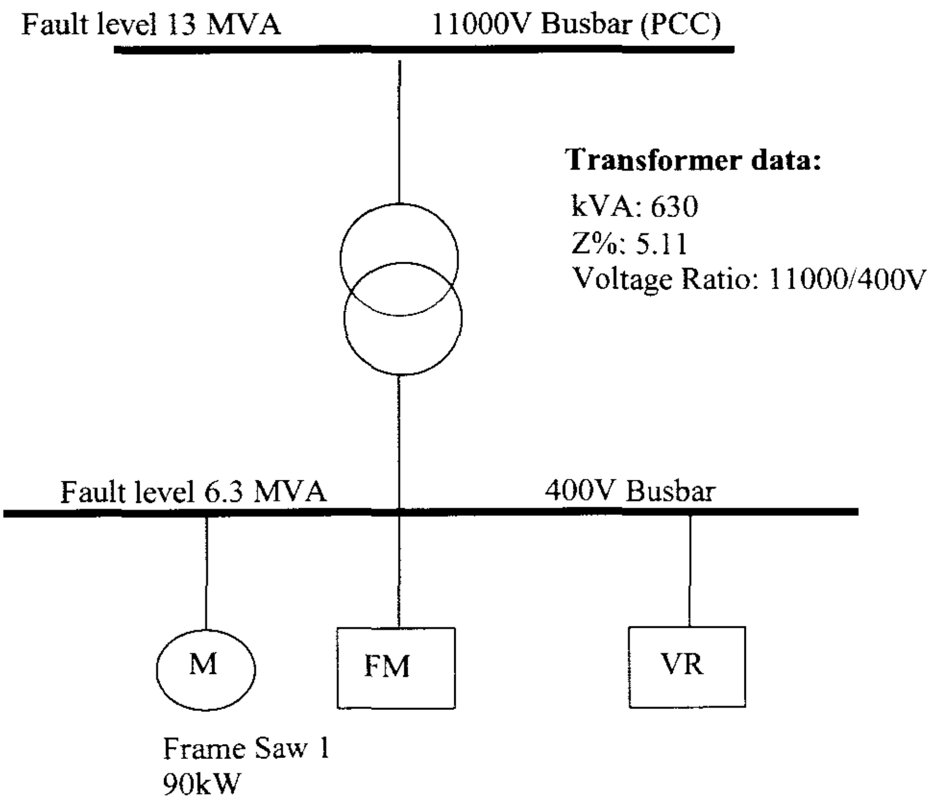

Figure 4-2 Electrical Layout of Sawmill A

The flicker level for this Frame Saw was measured as shown in Figure 4.3. These measurements were taken on 7 November 2002.

As the Multi-rip Saw does not contribute significantly to the flicker as previously described, flicker measurements were done on the Frame Saw only. This production line operates from 07h00 to 17h00 weekdays only.
The assessed flicker level for this Frame Saw is $P_{st} = 2$ as indicated by the dotted line (A) in Figure 4.3.

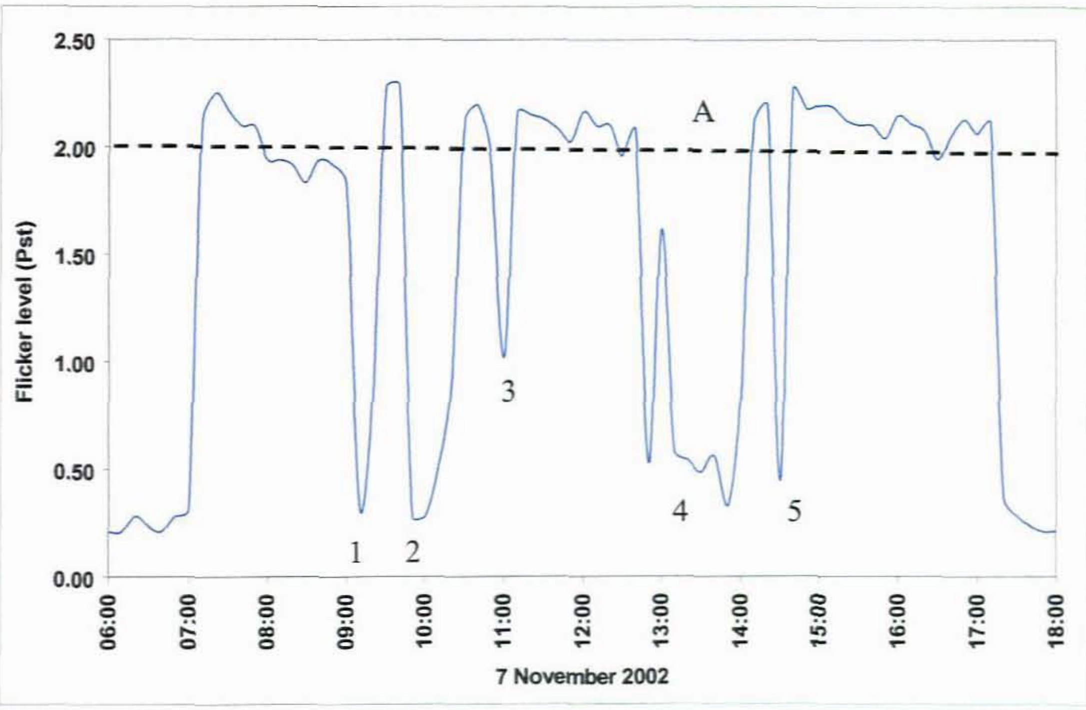

Figure 4-3 Total Flicker Level Measured for Frame Saw 1

The flicker levels were at its minimum indicated by point (1) due to a breakdown on the Frame Saw and at point (2) when it was tea time. At point (3) the flicker level came down to a $P_{st} = 1$ for a short period when the Frame Saw was stopped due to a log pile up at the Multi-rip Saw. At point (4) the flicker levels were also at its minimum when the plant was not operational during lunch. Point (5) also indicates a minimum flicker level due to the stop and start of the Frame Saw.

Case Study 1	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Sawmill A	Frame Saw 1	90	303	1.2	6.3	2.00	139

Table 4-1 Summary of Results for Sawmill A

The Frame Saw flywheel dimensions and speeds were measured. The fault levels were calculated at the point of measurement. The method used to typically calculate these fault levels is indicated in appendix A. With the use of the empirical formula (See Chap. 1, equation 1.1) the K_{sm} factors were calculated for the Frame Saw. A summary of the results is tabulated in Table 4.1.

4.3 Case Study 2 – Sawmill B

The electrical layout for this plant is shown in Figure 4.4. This sawmill is located in the Southern Cape region where the harder type of Pine trees are found. The flicker meter (FM) and the voltage recorder (VR) were connected to the 400V secondary side of the transformer. The total flicker was measured on the 400V busbar. Sawmill B consisted of a Frame Saw. The Frame Saw is driven by a 110kW motor.

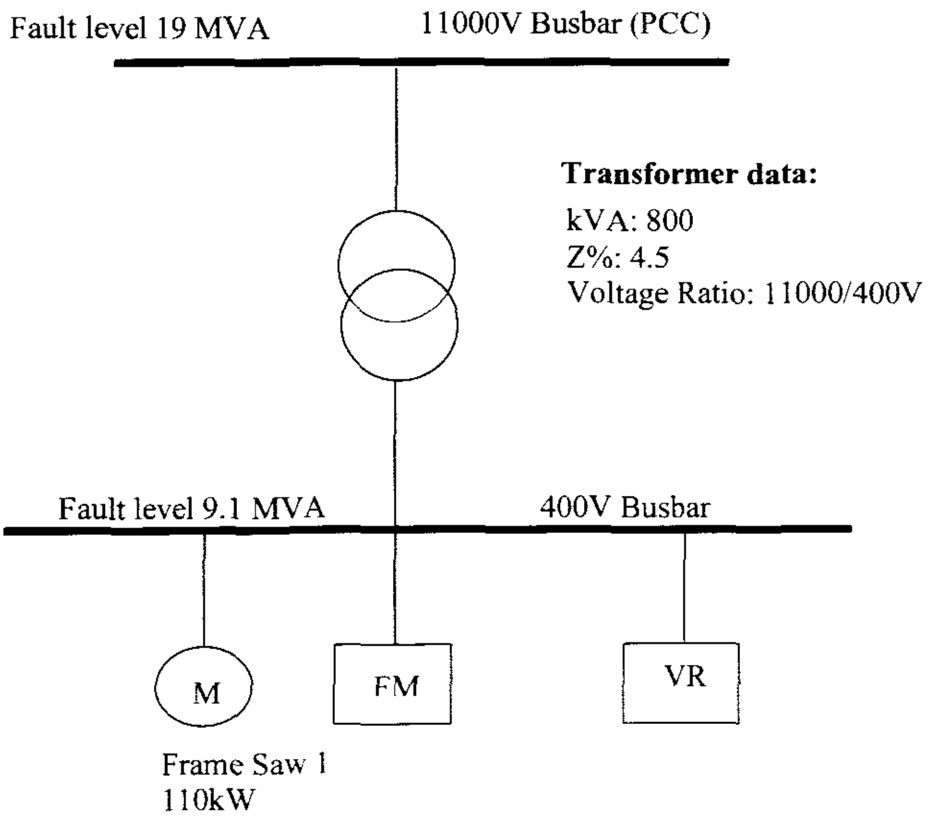

Figure 4-4 Electrical layout of Sawmill B

The flicker level for this Frame Saw was measured as shown in Figure 4.5. These measurements were taken on 3 June 2003.

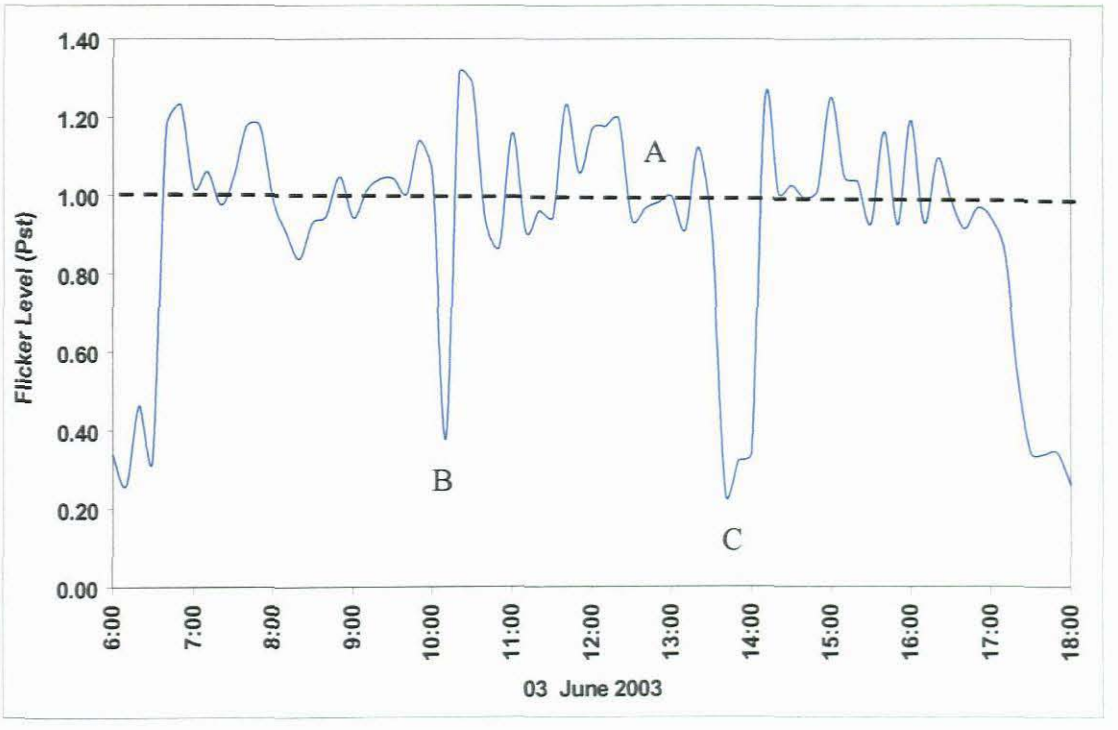

Figure 4-5 Total Flicker Level Measured for Frame Saw 1

This production line operates 24 hours a day, five days a week. The day shift starts from 07h00 to 17h15 and night shift from 19h00 to 05h15. The flicker level for the Frame Saw was assessed at $P_{st} = 1$ as indicated by the dotted line (A) shown in Figure 4.5. Point (B) and (C) indicates a reduction in flicker levels, this is due to the shut down for tea at 10h00 and lunch at 13h30 respectively.

Case Study 2	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Sawmill B	Frame Saw 1	110	309	1.35	9.1	1.00	83

Table 4-2 ***Summary of Results for Sawmill B***

Flywheel dimensions and speeds were also taken for the Frame Saw. The fault levels were calculated at the point of measurement. The method typically used to calculate these fault levels is indicated in appendix A. The K_{sm} factors were calculated for the Frame Saw with the use of the empirical formula (See Chap. 1, equation 1.1). A summary of the results is tabulated in Table 4.2.

4.4 Case Study 3 – Sawmill C

The electrical layout for this plant is shown in Figure 4.6. This sawmill is located in the Southern Cape region where the harder type of Pine trees are found. The supply transformer for this sawmill is 11000/3300V. A 3300/400V intermediate transformer is being used for the 400V supply to the sawmill loads. The flicker meter (FM) and the voltage recorder (VR) were connected to the 400V secondary side of the transformer. The total flicker was measured on the 400V busbar. Sawmill C consisted of a Frame Saw. This Frame Saw is driven by a 110kW motor.

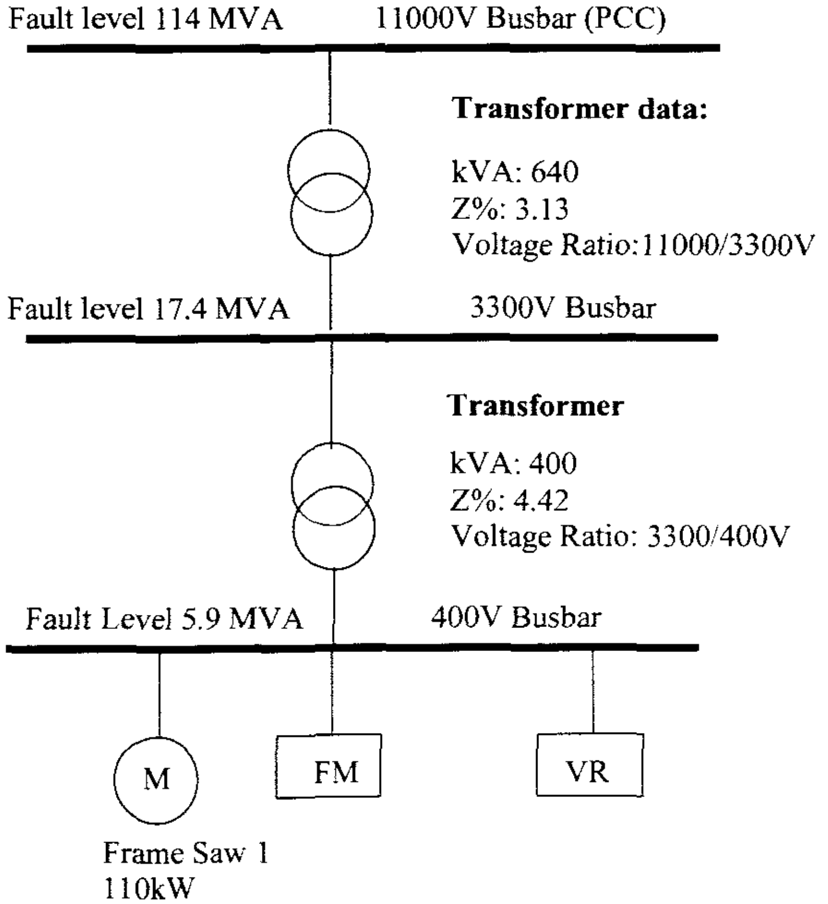

Figure 4-6 Electrical Layout for Sawmill C

The flicker level for this Frame Saw was measured as shown in Figure 4.7. These measurements were taken on 5 June 2003. This production line operates from 07h00 to 17h15 weekdays only.

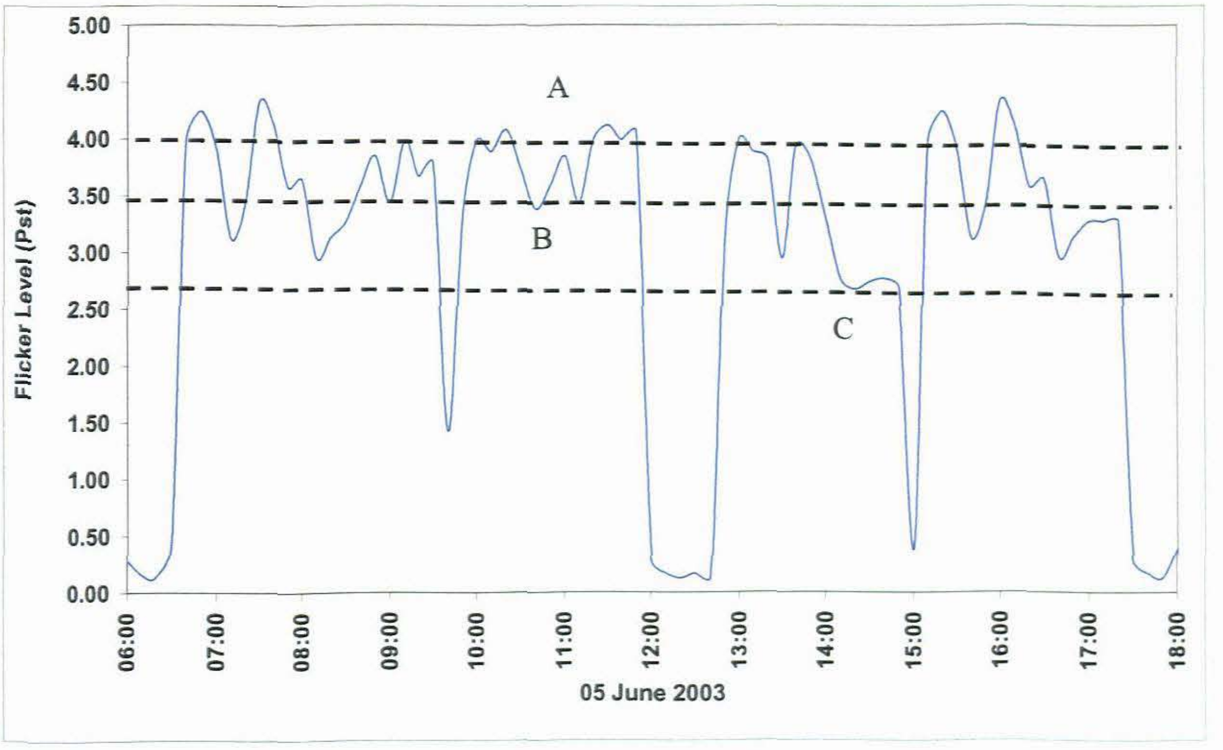

Figure 4-7 Total Flicker Level Measured for Frame Saw 1

At this sawmill a clear distinction as compared to sawmill A, in the flicker levels could be made between a soft and a hard type of Pine wood. When a harder type of Pine is being cut the flicker levels varies significantly from a $P_{st} = 3.5$ to $P_{st} = 4$ as indicated by the dotted lines at points (A) and (B) respectively. The dotted line (C) indicates a $P_{st} = 2.8$ as the assessed flicker when the frame saw is running no load. There is also a significant difference in flicker levels between load and no load flicker which varies from 25% to 42%. Due to the negligible effect on the flicker between load and no load at the other sawmill plants (Sawmill A and B) a $P_{st} = 2.8$ (no load flicker level) was used to calculate the K_{sm} factor to ensure consistency with other sawmills.

Case Study 3	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Sawmill C	Frame Saw 1	110	315	1.24	5.9	2.80	150

Table 4-3 Summary of the Results for Sawmill C

The fault levels were calculated at the point of measurement. The method typically used to calculate these fault levels is indicated in appendix A. Flywheel dimensions and speeds were taken for this Saw. Using the empirical formula (See Chap. 1, equation 1.1) the K_{sm} factors were calculated for the respective saws. A summary of the results is tabulated in Table 4.3.

4.5 Case Study 4 – Sawmill D

The electrical layout for this plant is shown in Figure 4.8. This sawmill is located in the Western Cape region where the softer type of Pine trees are found.

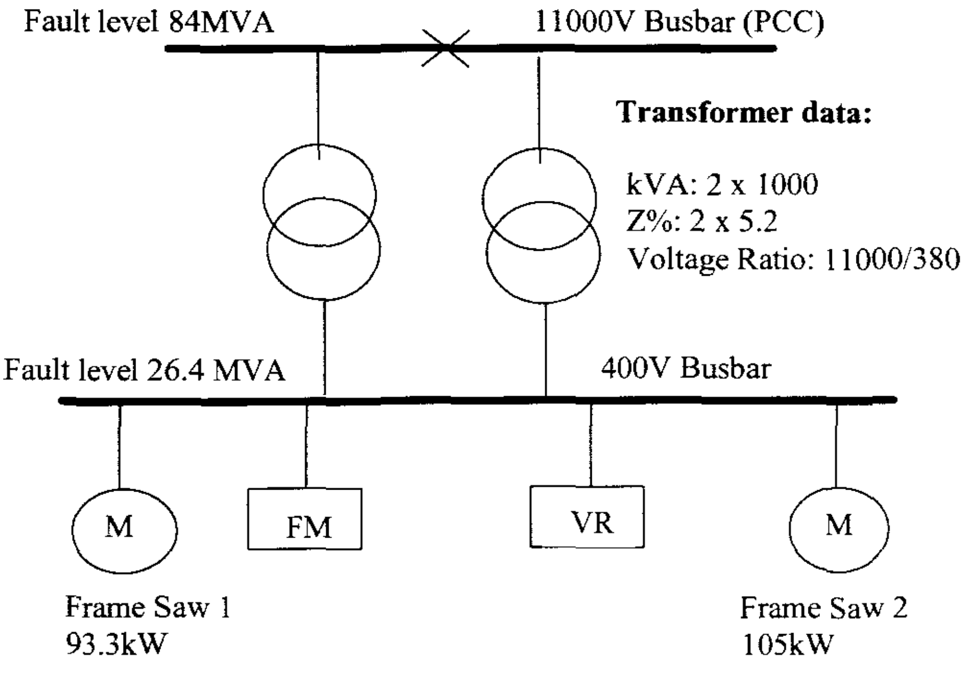

Figure 4-8 Electrical layout of Sawmill D

The flicker meter (FM) and the voltage recorder (VR) were connected to the 400V busbar, secondary side of the transformer. Sawmill A consisted of two Frame Saws operating in series. Frame Saw 1 is driven by a 93.3kW motor and Frame Saw 2 by a 105kW motor (see Chap. 2, Figure2.9).

The total flicker levels measured for both Frame Saws are shown in Figure 4.9. These measurements were taken on 13 November 2002. The total flicker levels are measured when both Frame Saws are in operation.

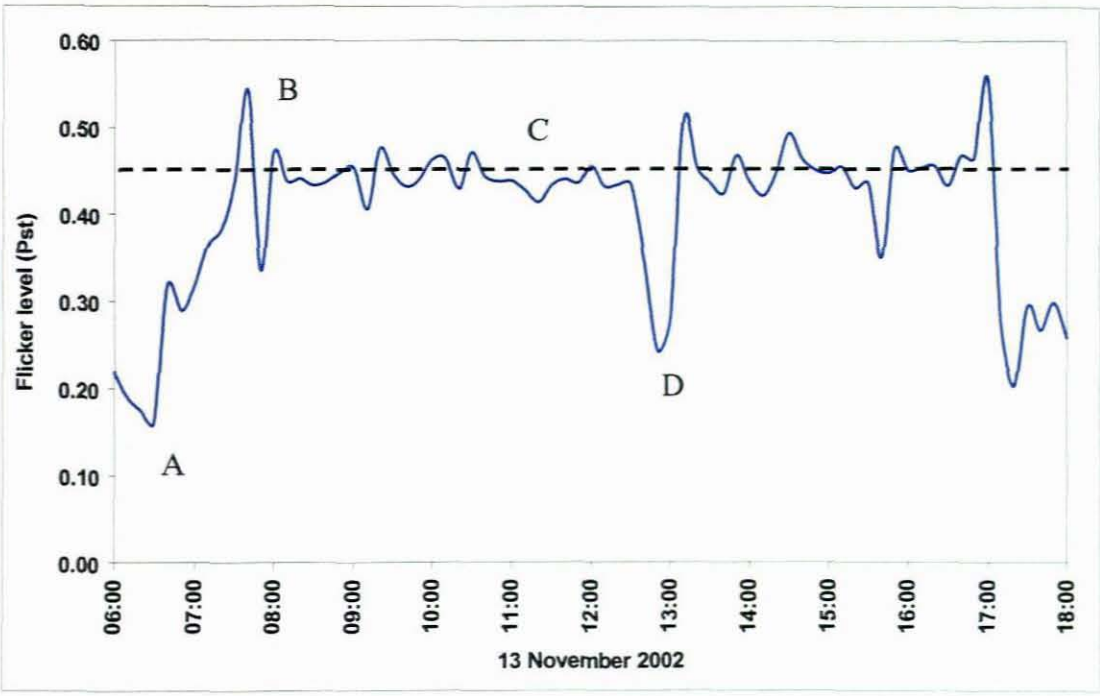

Figure 4-9 Total Flicker Levels Measured for Both Frame

This production line operates 24 hours a day, five days a week. The day shift starts from 07h30 to 17h00 and night shift from 19h30 to 05h00. When the plant is not in operation from 05h00 to 07h00 and 17h00 to 19h00, the background flicker levels was measured as indicated by point (A), and is assessed to be $P_{st} = 0.2$. The background flicker refers to the flicker level present on the 400V busbar when the sawmill is not in operation. The trended flicker levels measured on the 400V busbar for the Frame Saws can be assessed as being $P_{st} = 0.43$ as indicated by the dotted line (C) in Figure 4.9. At start-up of the Frame Saws the flicker levels can be assessed as $P_{st} = 0.53$ as indicated by point (B) in Figure 4.9. This level is higher due to the high currents being drawn by the motor when it is started and thereby causing the voltage drop. This voltage drop thereby causing a higher flicker level. Point (D) indicates a reduction in flicker levels, this is due to the shut down in operation for lunch.

From 17h00 the plant was inoperative until the next shift starts. Each Frame Saw was run individually, during lunch, to determine their flicker levels. Frame Saw 1 flicker level was assessed at a $P_{st} = 0.35$ and Frame Saw 2, $P_{st} = 0.33$. To verify the total flicker that was measured in Figure 4.9 the "Cubic Summation Law" (See Chap. 2, equation 2.1) is used.

$$P_{st}(\text{total}) = \sqrt[3]{(0.35)^3 + (0.33)^3}$$
$$P_{st}(\text{total}) = 0.43$$

The total flicker calculated $P_{st} = 0.43$ is representative of the total flicker measured as shown in Figure 4.9 by the dotted line (C).

Flywheel diameters (Ø) and speeds were also taken for each Frame Saw. The fault levels were calculated at the point of measurement. K_{sm} factors were calculated for the respective saws. A summary of the results is tabulated in Table 4.4.

Case Study 4	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Sawmill D	Frame Saw 1	93.3	312	1.5	26.4	0.35	100
	Frame Saw 2	105	320	1.35	26.4	0.33	83

Table 4-4 Summary of the Results for Sawmill D

4.6 Case Study 5 – Sawmill E

The electrical layout for this plant is shown in Figure 4.10. This sawmill is located in the Southern Cape region where the harder type of Pine trees are found.
The flicker meter (FM) and the voltage recorder (VR) were connected to the 400V secondary side of the transformer. The total flicker was measured on the 400V busbar. Sawmill E consisted of two Frame Saws operating in series. Frame Saw 1 is driven by a 45kW motor and Frame Saw 2 by a 60kW motor (see Chap. 2, Figure 2.9).

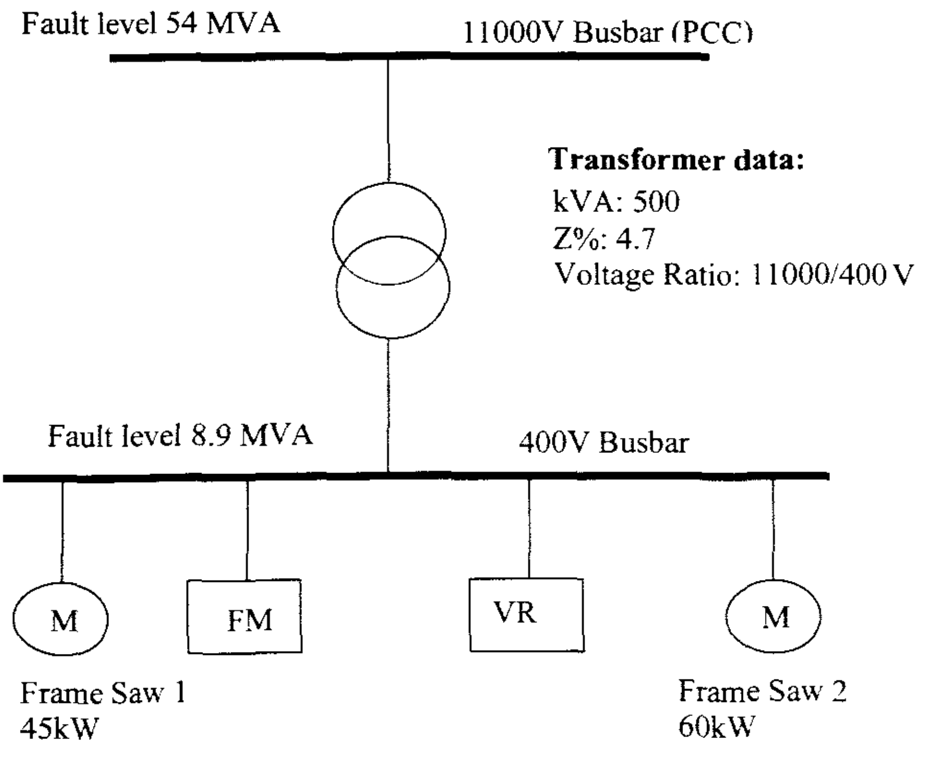

Figure 4-10 Electrical Layout for Sawmill E

The total flicker levels measured for the two Frame Saws when both saws were in operation is shown in Figure 4.11. These measurements were taken on 14 November 2002.

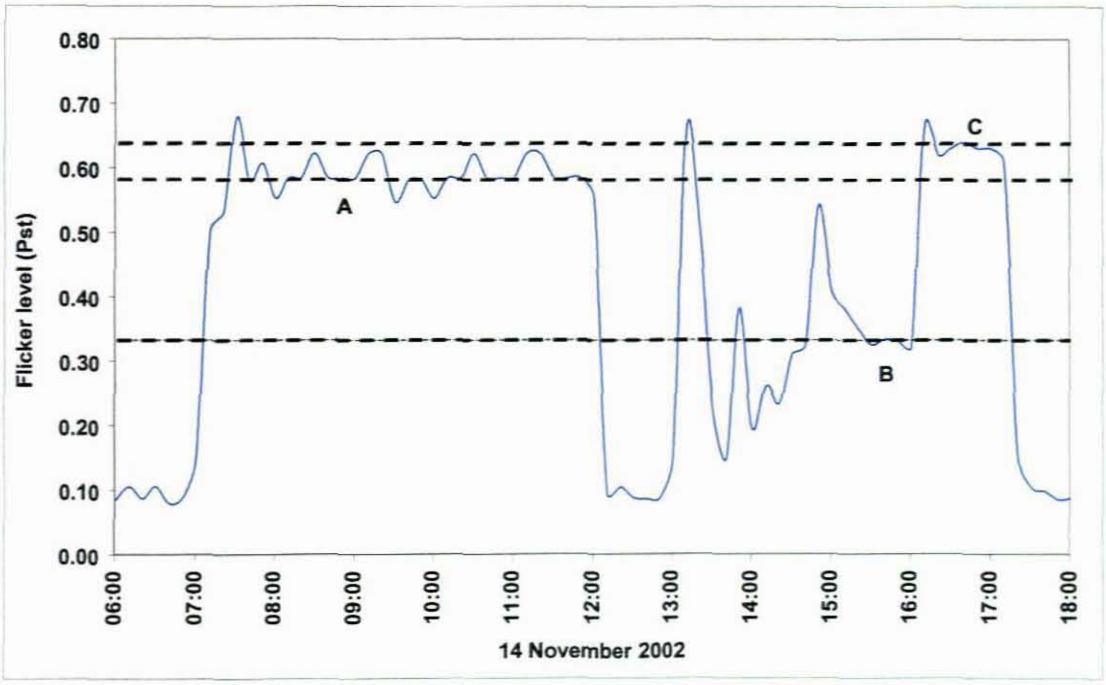

Figure 4-11 Individual and Total Flicker Levels Measured Both Frame Saws

This production line operates from 07h00 to 17h15 weekdays only. As illustrated in Figure 4.11 Frame Saw 1 assessed flicker level is a $P_{st} = 0.58$ indicated by the dotted line (A) and for Frame Saw 2 $P_{st} = 0.33$ indicated by the dotted line (B). The total flicker level when both Frame Saws were running was assessed to be $P_{st} = 0.62$, indicated by the dotted line (C) in Figure 4.11. The flicker levels were at its minimum from 12h00 to 13h00 this was during lunch period. After lunch Frame Saw 1 was started and stopped half an hour later to replace the blades. The blades need to be sharpened to ensure that the cutting process runs smoothly. If it is not sharp the logs can be cut skew which will have a huge impact on the quality of the production. Both saws were off during this period. Frame Saw 2 was started at 14h43 while Frame Saw 1 was still off. From 16h00 Frame Saw 1 was started while Frame Saw 2 was still running. Both Frame Saws were operational until 17h15.

To verify the total flicker that was measured in Figure 4.11, the "Cubic Summation Law" (See Chap. 2, equation 2.1) is used. This law is used to summate the two Frame Saws flicker levels. The calculation method corresponds to the total flicker that was measured for the two Frame Saws therefore the total flicker calculated $P_{st} = 0.62$ is representative of the total flicker measured as shown in Figure 4.11.

$$P_{st}(\text{total}) = \sqrt[3]{(0.58)^3 + (0.33)^3}$$
$$P_{st}(\text{total}) = 0.62$$

Case Study 5	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Sawmill E	Frame Saw 1	45	251	1.24	8.9	0.58	114
	Frame Saw 2	60	296	1.2	8.9	0.33	49

Table 4-5 Summary of the Results for Sawmill E

A summary of the results for case study 5 is tabulated in Table 4.5.

4.7 Case Study 6 – Sawmill F

This plant is not connected to the utilities electrical network and uses its own steam generators to supply their electrical loads. Both generators were in operation when the measurements were performed. The electrical layout for this plant is shown in Figure 4.12. This sawmill is located in the Eastern Cape region where the harder type of Pine trees are found. The flicker meter (FM) and the voltage recorder (VR) were connected on the 11000V busbar.

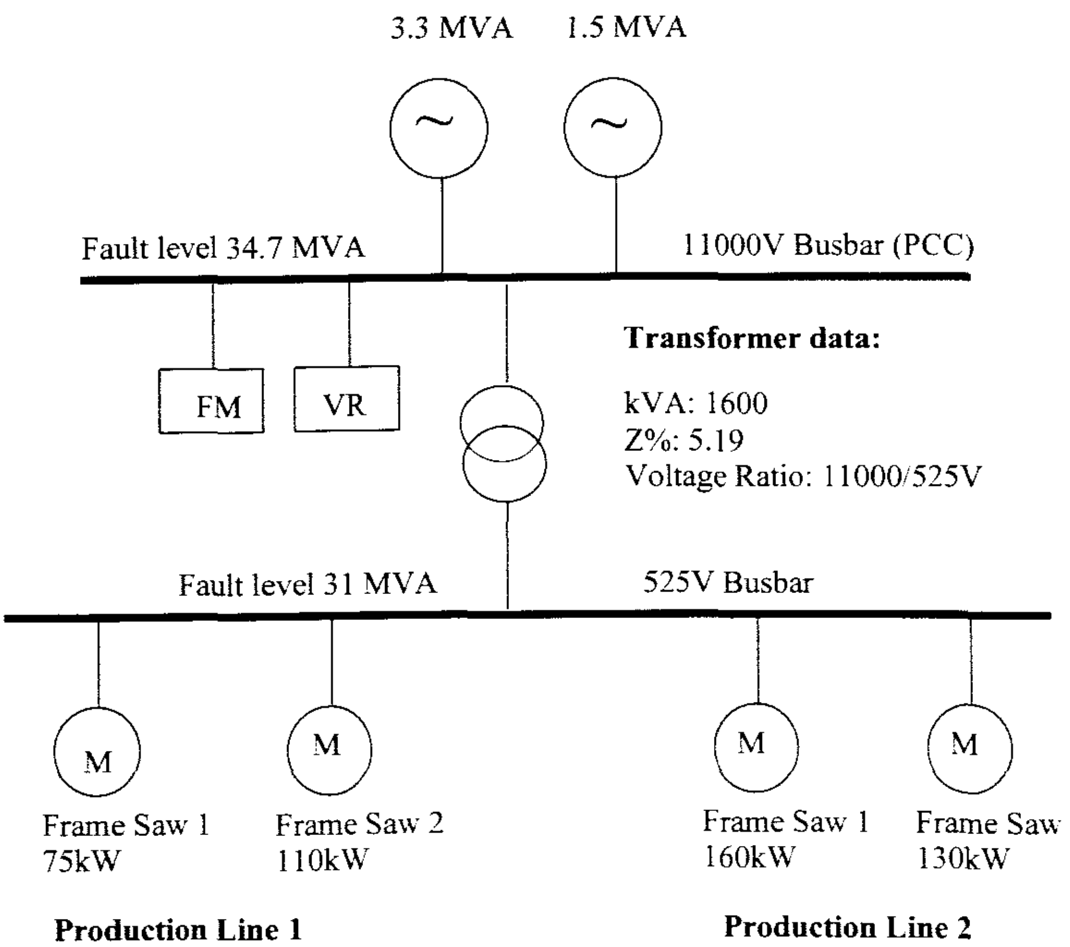

Figure 4-12 Electrical Layout for Sawmill F

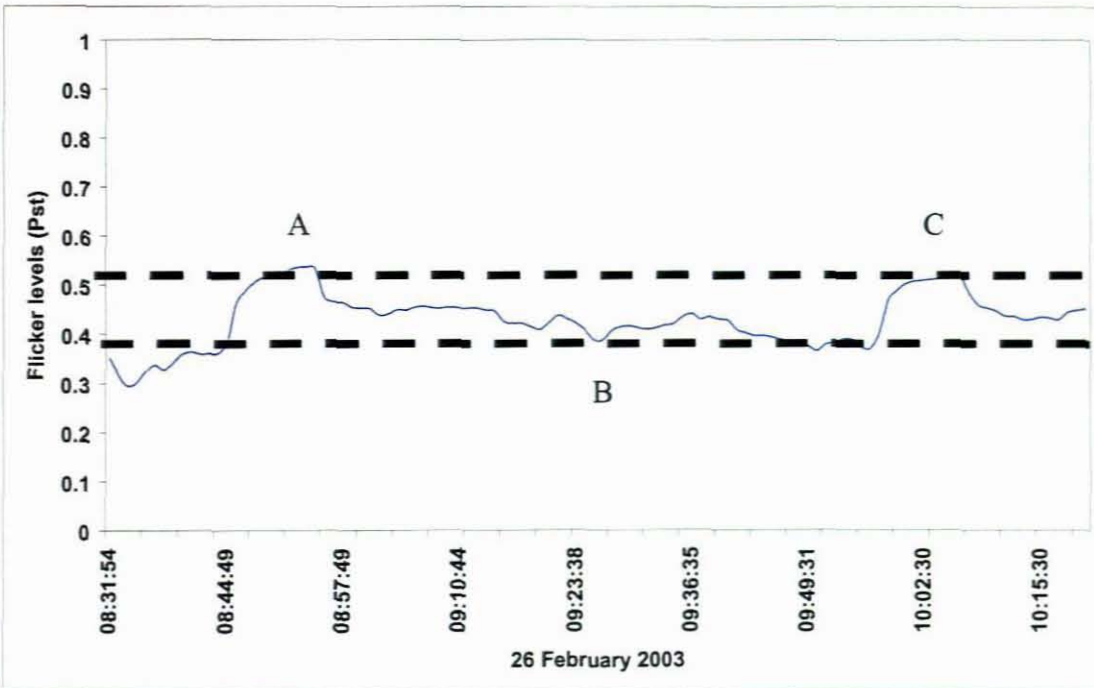

Figure 4-13 Total Flicker Level Measured for all Frame Saws

Sawmill F consisted of two independent production lines. Production line 1 consisted of two Frame Saws, which operated, in series as well as production line 2. Frame Saw 1 and 2 for production line 1 was driven by a 75kW and 110kW motor respectively. Production line 2, Frame Saw 1 and 2 was driven by a 160kW motor and 130kW motor respectively.

The total flicker levels for all the Frame Saws were measured as shown in Figure 4.13. These measurements were taken on 26 February 2003. Individual flicker measurements were done during lunch breaks to assess the flicker levels of each Frame Saw in order to calculate the K_{sm} factors. This production line operates 24 hours a day, five days a week. The day shift starts from 06h30 to 17h00 and night shift from 18h30 to 05h00.

When the four Frame Saws were started the total flicker levels were at a P_{st} = 0.51 as indicated by dotted line at points (A and C) in Figure 4.13. The individual flicker levels was assessed at Pst = 0.39 as indicated by the dotted line (B).

Case Study 6	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Sawmill F Production line 1	Frame Saw1	75	256	1.34	31.0	0.39	161
	Frame Saw2	110	324	1.16	31.0	0.39	110
Production line 2	Frame Saw1	160	295	1.16	31.0	0.39	76
	Frame Saw2	130	316	1.16	31.0	0.39	93

Table 4-6 Summary of the Results for Sawmill F

A summary of the results for case study 6 is tabulated in Table 4.6.

4.8 Case Study 7 – Sawmill G

This plant is not connected to the utilities electrical network and uses its own steam generators to supply their electrical loads. Both generators were in operation when the measurements were performed. The electrical layout for this plant is shown in Figure 4.14. This sawmill is located in the Eastern Cape region where the harder type of Pine trees are found. This was the only sawmill site where Eucalyptus trees are cut. These types of trees are a very hard in comparison with the Pine trees see Chapter 2, Table 2.3.
The flicker meter (FM) and the voltage recorder (VR) were connected on the 400V busbar. Sawmill G consisted of a Pine line and a Eucalyptus also known as a Karri line. These lines refer to the different types of wood that was being cut for production purposes.

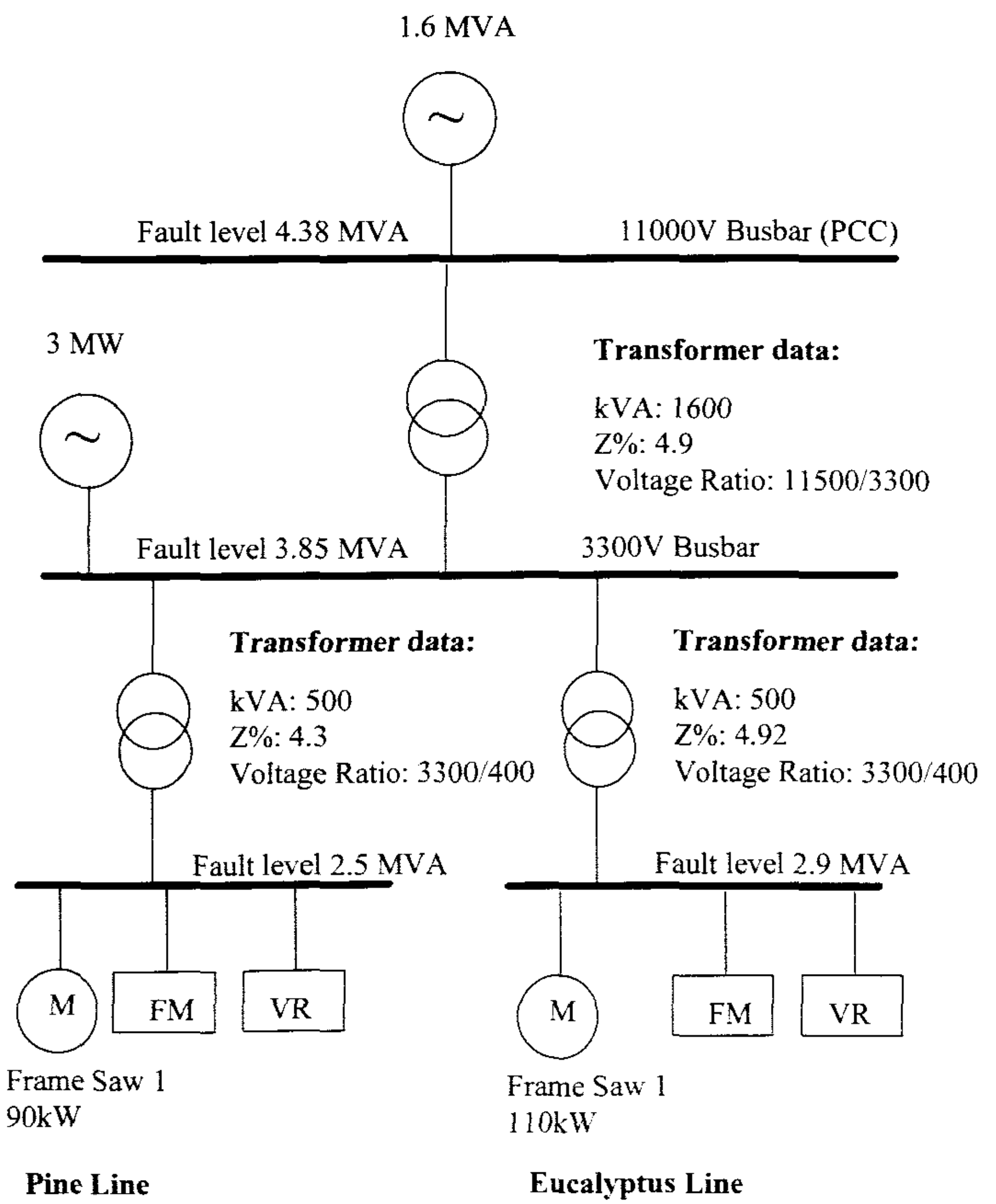

Figure 4-14 Electrical Layout of Sawmill G

The Pine line is driven by a 90kW motor and the Eucalyptus line with a 110kW motor. The flicker levels for the Pine line Frame Saw was measured as shown in Figure 4.15. These measurements were taken on 26 February 2003.

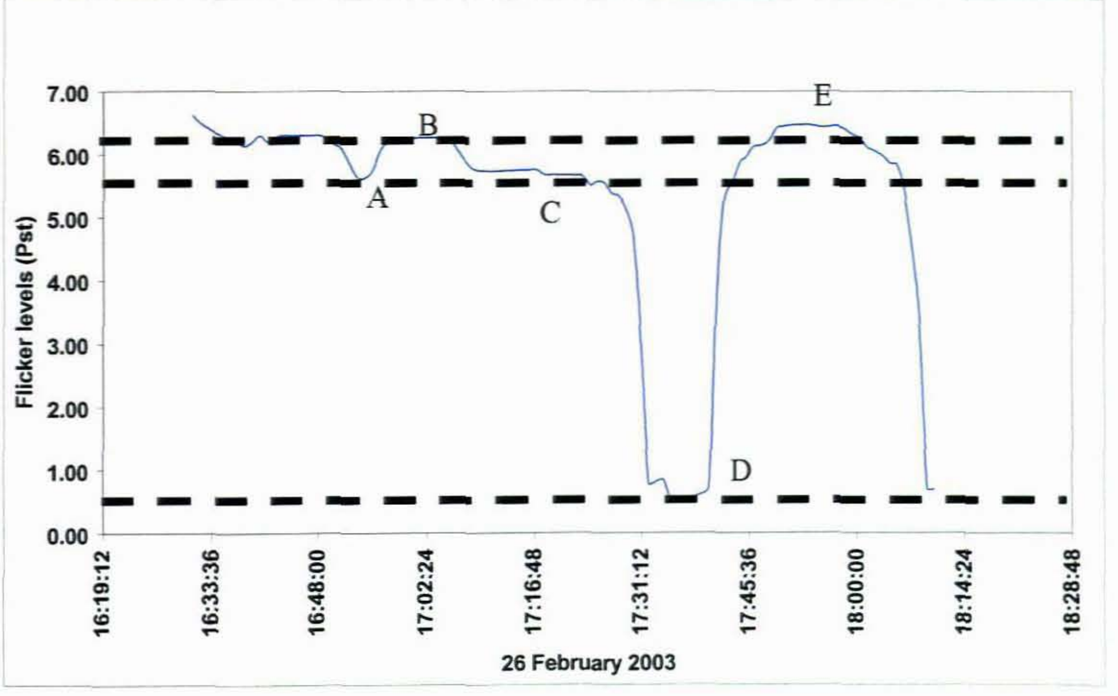

Figure 4-15 Total Flicker Measured for Pine Line Frame Saw 1

A clear distinction is visible at this sawmill between the no load and on load flicker levels. The no load flicker levels indicated by the dotted line at points (A) and (C) in Figure 4.15 was assessed at a $P_{st} = 5.7$. The load flicker levels are indicated by the dotted line at points (B) and (E) and was assessed at a $P_{st} = 6.4$. When this production is inoperative the background flicker was assessed at a $P_{st} = 0.8$ indicated by the dotted line (D). There is a significant difference in the flicker levels between load and no load levels of 12% at this sawmill. Due to a negligible effect on the flicker between load and no load at the previously mentioned sawmill plants a $P_{st} = 5.7$ (no load flicker level) was used to calculate the K_{sm} factor to ensure consistency with other sawmills.

The flicker levels for the Eucalyptus line Frame Saw was measured as shown in Figure 4.16. These measurements were taken on 26 February 2003.

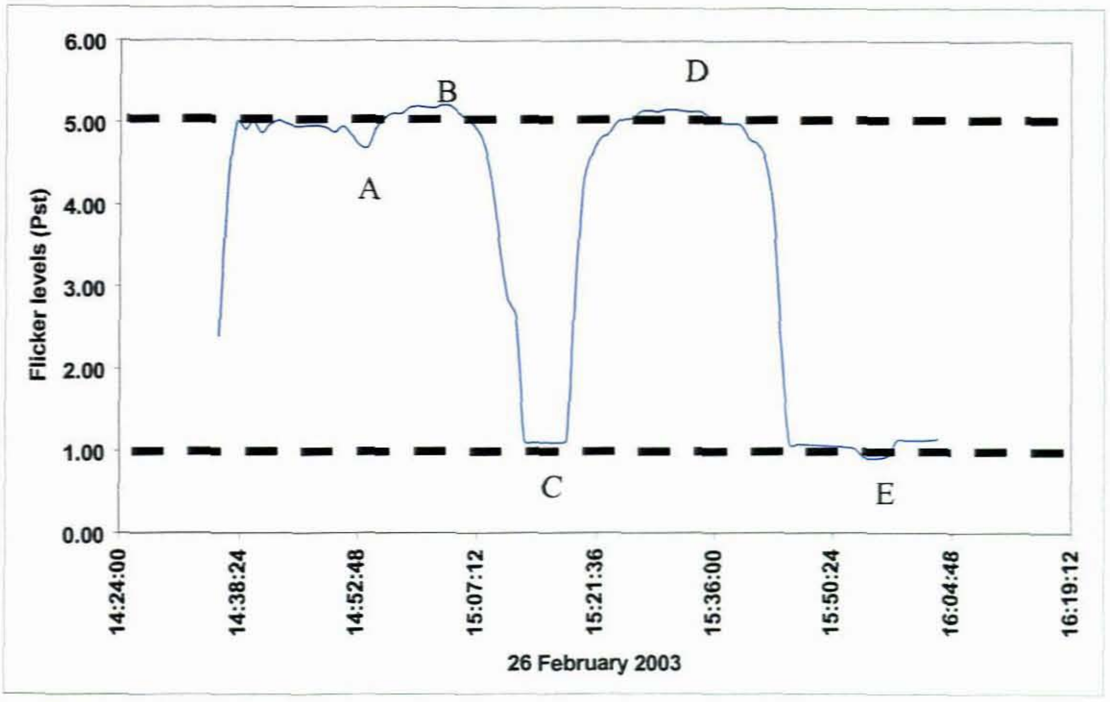

Figure 4-16 Total Flicker Measured for Eucalyptus Line Frame Saw 1

The Eucalyptus line for sawmill G also has a noticeable difference between the load and no load flicker levels. The no load flicker level indicated by point (A) as shown in Figure 4.16 was assessed at a $P_{st} = 4.9$. The load flicker levels is indicated by the dotted line at points (B) and (D) was assessed at a $P_{st} = 5.1$. When this production is inoperative the background flicker was assessed at a $P_{st} = 1$ indicated by the dotted line at points (C) and (E). Due to a negligible effect on the flicker between load and no load at the previously mentioned sawmill plants a $P_{st} = 4.9$ (no load flicker level) was used to calculate the K_{sm} factor to ensure consistency with other sawmills.

Case Study 7	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Sawmill G							
Pine Line	Frame Saw1	90	304	1.5	2.5	5.70	158
Eucalyptus line	Frame Saw1	110	281	1.5	2.5	4.90	111

Table 4-7 Summary of the Results for Sawmill G

A summary of the results for case study 7 is tabulated in Table 4.7.

4.9 Summary

Flicker measurements were performed at various geographically located sawmill plants. With the use of the empirical formula, K_{sm} factors were calculated for the Frame Saws. At sawmills where there was a significant difference in flicker levels between the load and no load values, the no load values was used to calculate the K_{sm} factors. This is to ensure consistency for all calculated K_{sm} factors. The flicker meter and voltage recorder was installed at the 400V busbars at all sawmill plants to ensure consistency in the measurements.

At one sawmill plant it was possible to perform the measurements on the 11000V busbar by means of a 11000/110V metering voltage transformer. Measurements were performed at eight sawmill plants and a total of 15 K_{sm} factors were calculated.

Chapter 5

5 Comparative Analysis of K_{sm} Factors

In this chapter the K_{sm} factors calculated at the various sawmill plants are compared to determine the accuracy. Reasons for the difference in the K_{sm} factors are also discussed.

5.1 Comparison of Different K_{sm} Factors

Table 5.1 indicates the 9 sawmills that were investigated with a total of 15 K_{sm} factors. The table indicates the geographical locations of the sawmills as well as the motor sizes and flywheel speeds of the Frame Saws. The table also indicates the calculated LV fault levels at the point of measurement and the measured flicker levels for each sawmill. The K_{sm} factors are compared with the benchmark sawmill as well with the various sawmills in order to determine the accuracy of the K_{sm} factors.

Case Studies	Sawmill Location	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Benchmark Sawmill	Western Cape	Frame Saw1	132	306	1.35	7.0	0.97	51
		Frame Saw2	132	328	1.35	7.0	0.75	40
Sawmill A	Western Cape	Frame Saw1	90	303	1.2	6.3	2.00	139
Sawmill B	Southern Cape	Frame Saw1	110	309	1.35	9.1	1.00	83
Sawmill C	Southern Cape	Frame Saw1	110	315	1.24	5.9	2.80	150
Sawmill D	Western Cape	Frame Saw1	93.3	312	1.5	26.4	0.35	100
		Frame Saw2	105	320	1.35	26.4	0.33	83
Sawmill E	Southern Cape	Frame Saw1	45	251	1.24	8.9	0.58	114
		Frame Saw2	60	296	1.2	8.9	0.33	49
Sawmill F Production Line 1	Eastern Cape	Frame Saw1	75	256	1.34	31.0	0.39	161
		Frame Saw2	110	324	1.16	31.0	0.39	110
Sawmill F Production Line 2		Frame Saw1	160	295	1.16	31.0	0.39	76
		Frame Saw2	130	316	1.16	31.0	0.39	93
Sawmill G Pine Line	Eastern Cape	Frame Saw1	90	304	1.5	2.5	5.70	158
Sawmill G Eucalyptus Line		Frame Saw1	110	281	1.5	2.5	4.90	111

Table 5-1 Summary of Comparative Results

As the mechanical operation of the Frame Saws, are similar, the flicker levels of Frame Saws should also be similar for a specific sawmill where the fault levels and motor sizes are the same. From Table 5.1 this is not the case if the K_{sm} factors are compared for a sawmill with two Frame Saws like the benchmark sawmill. At each sawmill, the K_{sm} factors for Frame Saw 1 and 2 were compared and found to be different.

At sawmill A, K_{sm} factor for Frame Saw 1 is more than double that of the benchmark sawmill. At sawmill B, Frame Saw 1 K_{sm} factor is almost double that of the benchmark sawmill. At sawmill D, K_{sm} factors for Frame Saw 1 and 2 are almost double that of the benchmark sawmill. At sawmill E, Frame Saw 1 K_{sm} factor is double that of the benchmark sawmill but the K_{sm} factor for Frame Saw 2 is almost the same as the benchmark sawmill.

According to the operational and maintenance manual of these machines the rated size motors should be in the range of 90 to 110kW [22]. According to this, the motors used at sawmill E are undersized.

The K_{sm} factors at sawmills B and D are both 83. At both sawmills the Frame Saws were used in the secondary sawing process.

At sawmill C and G a clear distinction could be made between load and no load flicker levels. At these sawmills the difference in flicker levels can possibly be attributed to mechanical properties of the timbers as well as the mechanical variables of the Frame Saws.

It is considered that the different K_{sm} factors can be due to the mechanical variables concerning the Frame Saws. These include the direct and indirect method of connection from the motor to the flywheels, different size flywheels, different tensioning on vee-belts, different counter weights on flywheels and also different flywheel speeds. The K_{sm} factors are considered also to be affected by the different density and hardness of the type of wood being cut as described in Chapter 2, Table 2.5. The higher density trees are commonly found in the Southern and Eastern Cape regions of South Africa [16].

The higher density type Pine trees are known as Pinus pinaster and Pinus radiata (See Chapter 2, Table 2.5). The difference in the average density within these species is approximately 21%. The Eucalyptus tree commonly known as Karri has got a higher density and hardness compared to Pine trees. For this reason it can be assumed that the flicker emission would be higher for the Eucalyptus trees. It can be assumed that with a higher density and hardness of the wood a greater torque would be required and consequently higher load current therefore higher flicker emission.

K_{sm} factors that correlate are 139,150,158 and 161. At all these sawmills the Frame Saws were used in the primary sawing process. Also all the motor sizes were within the specification for the machines, except the one with a K_{sm} factor of 161.This undersize motor requires a greater torque to operate the Frame Saw and therefore higher load current is needed. This causes a increase in flicker levels and thereby increasing the K_{sm} factor. K_{sm} factors 76,83,83 and 93 correlates. At these sawmills the Frame Saws were used in both primary and secondary processes as well as K_{sm} factors 100,110,114, 129 and 40,49 and 51.

From Table 5.1 the K_{sm} factors 51 and 40 of the benchmark sawmill will be ignored due to the customer transformer that was refurbished at this plant and the transformer specification nameplate remained the same. The impedance could have change due to the refurbishment, also the assumption was made that the transformers are not connected in parallel due to the absence of single line diagrams from customer. Frame Saw 2, K_{sm} factor of 49 at sawmill E was ignored because, this motor was rewound and the correct ratings of the motor after rewiring could not be established. Frame Saw 1 of production line 1 K_{sm} factor of 161 at sawmill F was also ignored due to the motor being under rated for this application to operate the Frame Saw.

5.2 Statistical Analysis

From the 15 K_{sm} factors 11 remains after the elimination of certain K_{sm} factors. These 11 K_{sm} factors range from a minimum of 76 to a maximum of 158 as indicated by the dotted lines at points (A) and (B) respectively in Figure 5.1.

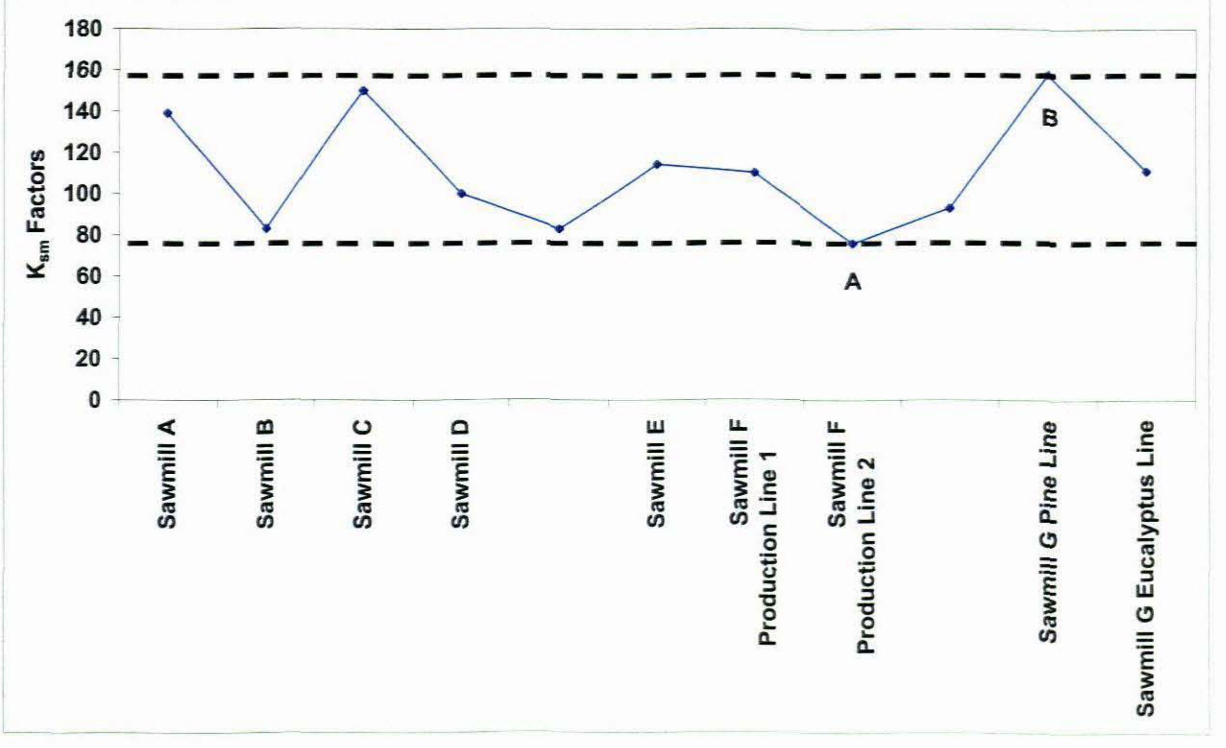

Figure 5-1 K_{sm} Factors for Various Sawmill Plants

For flicker prediction purposes it is difficult to select a single value from the K_{sm} factors indicated in Table 5.2. From these K_{sm} factors in Table 5.2 a optimal K_{sm} needs to be statistically determined which can be used together with the empirical formula to predict the flicker emission of sawmill plants.

List of K_{sm} factors			
139	83	150	158
100	83	114	111
110	76	93	

Table 5-2 K_{sm} Factors

The mean value can be calculated using the values in Table 5.2. The mean value of a set of measurements is the sum of the measurements divided by the number of measurements in the set [21]. The equation for the mean value is expressed as:

$$\bar{x} = \frac{\sum x}{n} \qquad (5.1)$$

Where,

$\bar{x}$ = sample mean

$\sum x$ = sum of measurements

n = number of measurements

Applying equation 5.4 to calculate the mean of the K_{sm} factor measurements:

Therefore,

$$\bar{x} = \frac{1217}{11}$$

$$= 111$$

This figure indicates that the average K_{sm} factor is 111.

5.3 Evaluation of Predicted and Measured Flicker Levels

To determine the accuracy and the use of the empirical formula with the K_{sm} factor of 111, a comparative analysis of the predicted to the measured flicker level is done.

Case Studies	Load	Measured Flicker Level (Pst)	Predicted Flicker Level (Pst) with Ksm =111	Percentage Variance
Sawmill A	Frame Saw1	2.00	1.60	25
Sawmill B	Frame Saw1	1.00	1.34	25
Sawmill C	Frame Saw1	2.80	2.07	35
Sawmill D	Frame Saw1	0.35	0.39	10
	Frame Saw2	0.33	0.44	25
Sawmill E	Frame Saw1	0.58	0.56	4
Sawmill F Production Line 1	Frame Saw2	0.39	0.39	0
Sawmill F Production Line 2	Frame Saw1	0.39	0.57	32
	Frame Saw2	0.39	0.47	17
Sawmill G Pine Line	Frame Saw1	5.70	4.00	43
Sawmill G Eucalyptus Line	Frame Saw1	4.90	4.90	0

Table 5-3 Comparative Analysis of Predicted to Measured Flicker Levels

Table 5.3 is a compilation of the remaining eleven K_{sm} factors, the original being fifteen, and illustrates the measured to predicted flicker levels and calculated variance at the various sawmills (See page 44). The percentage variance in Table 5.3 can be interpreted as an error margin.

From Table 5.3 a maximum error margin of 43% was calculated between the predicted and measured flicker levels at a single sawmill G.
Using an average calculated K_{sm} of 111 will give rise to an average error margin of approximately 20%. Therefore using the average error margin of 20% implies that for a measured $P_{st}=1$, the predicted P_{st} value would be $P_{st}=1.2$.

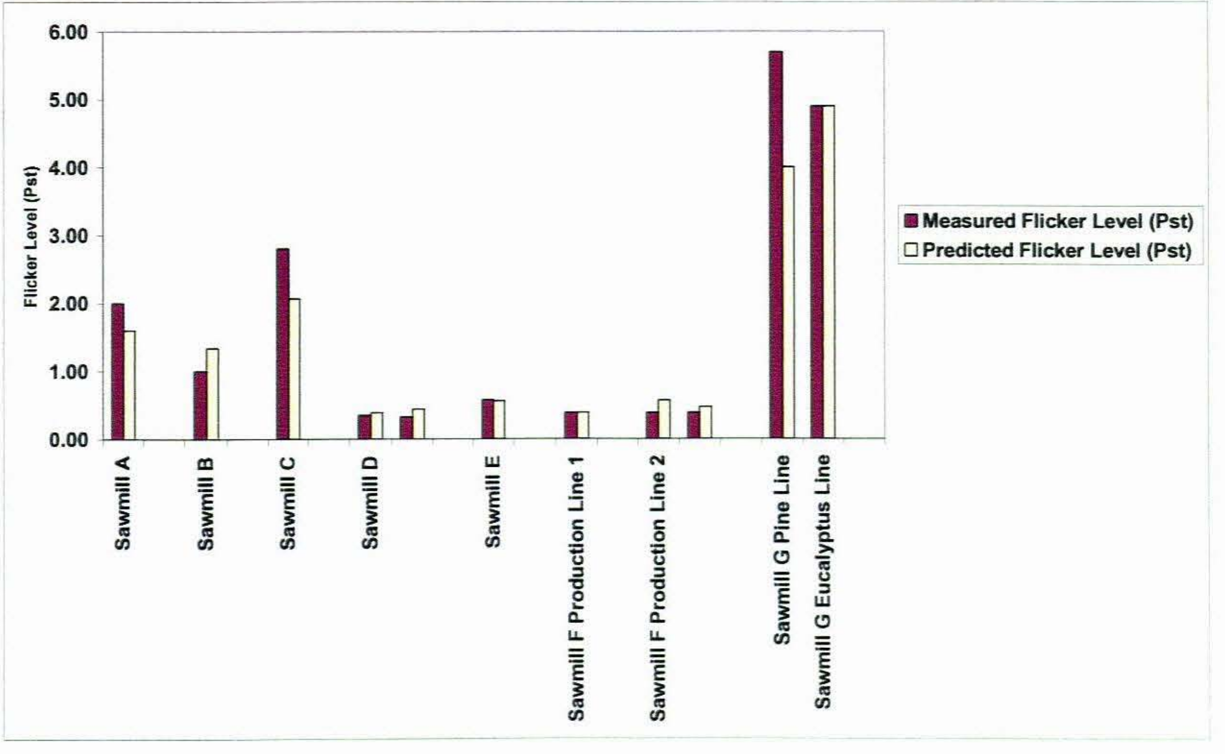

Figure 5-2 Predicted to Measured Level Variance

The percentage error between the predicted and the measured flicker levels for each sawmill plant is indicated in Figure 5.2. The percentage error that exists between the predicted and the measured flicker levels for the sawmill plants can be attributed to certain factors discussed in section 5.1 (page 44) which include:

- Mechanical variables of the Frame Saws. These include the direct and indirect method of connection from the motor to the flywheels, different size flywheels, different tensioning on vee-belts, different counter weights on flywheels and also different flywheel speeds.
- Mechanical properties of timber. This includes the different density and hardness of the type of wood being cut.

5.4 Implications of a Standard K_{sm} Factor

Using a standard $K_{sm}=111$ a worse case scenario with a maximum error margin of 43% from the predicted to measured flicker level at a single sawmill plant G is indicated by Table 5.3.
At these flicker levels the first option to be considered by the network planner is the utility procedure for evaluation of individual customer load emissions [5]. This procedure indicates three stages to be followed when connecting a new customer to the supply network. The utility needs to provide the customer with maximum allowable flicker emission levels. The levels are reflected in the supply contract with the customer [5].

- Stage 1 indicates that if the load is too small to impact on the PCC levels then a standard contractual clause will reflect in the customer contract.

- Stage 2 indicates, loads which may have an impact at the PCC are evaluated with respect to the existing flicker levels on the network. Specific contractual limits shall be reflected in the customer contract.
- Stage 3, where the emission level related to Stage 2 is difficult to achieve, detailed studies are undertaken to investigate the effects of allocating larger flicker levels to the customer. Where such allocations are made, the contract will specify the conditions under which these higher levels are allowed [5].

A second alternative at these levels the network planner will be triggered to consider various mitigation options to eliminate a possible flicker problem, which can include the following:

- Reconfigure the network to increase the fault level at the PCC (Point of Common Coupling).
- Increase the transformer size feeding the customer.
- Restrict the operating of the plant during the day only.
- Consider the possibility of using Multi-rip and Circular Saws instead of Frame Saws.

At certain sawmill plants the machinery is situated under a roof only with no supporting walls thereby allowing maximum daylight onto the working area. Under such circumstances a high flicker level could be present but the visibility or irritation of the flickering light would not be a problem due to the daylight. Also the customer can make use of fluorescent lights where the light intensity is less affected than the 60W 230V incandescent lamp for the same frequency of voltage fluctuations.

5.5 Summary

The K_{sm} factors for the various sawmills are compared to the benchmark sawmill, which was done with previous research. The benchmark sawmill plant was ignored due to the refurbished transformer and no single line diagrams available from the customer. Frame Saw 2, K_{sm} factor of 49 at sawmill E was ignored because, this motor was rewound and the correct ratings of the motor after rewiring could not be established. Frame Saw 1 of production line 1 K_{sm} factor of 161 at sawmill F was also ignored due to the motor being under rated for this application to operate the Frame Saw. An undersize motor causes a increase in the K_{sm} factor. From the 15 K_{sm} factors 11 remained. The K_{sm} factors range from a minimum of 76 to a maximum of 158. A mean Ksm factor of 111 was statistically determined. A significant difference between load and no load flicker levels can be attributed to the mechanical variables of the Frame Saws as well as the mechanical properties of the timber.

The average K_{sm} factor was calculated statistically. A K_{sm} factor of 111 was determined. A comparative analysis of the predicted to the measured flicker levels was done. A maximum percentage error margin of 43% was calculated at sawmill plant G. An average error margin of 20% was calculated. The implications of this error margin were discussed. The utility planner will be triggered to investigate further if necessary.

A K_{sm} factor of 111 represents a average value and can therefore be used at future sawmill plants to predict the flicker levels of the Frame Saws.

Chapter 6

6 Contributions and Closure

6.1 Contributions

1. A methodology was developed to predict flicker at sawmill plants.
2. The flicker levels were measured and assessed for 15 Frame Saws and a Circular and Multi-rip Saw.
3. Using the empirical formula K_{sm} factors were calculated for each of the respective loads.
4. These K_{sm} factors are only applicable on these types of saws operating under defined specified conditions.
5. A K_{sm} factor of 88 can be used for flicker prediction for the Circular Saw.
6. A K_{sm} factor of 19 can be used for flicker prediction for the Multi-rip Saw.
7. A K_{sm} factor of 111 can be used for flicker prediction for the Frame Saw.

6.2 Closure

1. The Circular and Multi-rip Saw have a negligible effect on the flicker.
2. The mechanical operating frequency of the Frame Saws is in the region of 5Hz which falls within the sensitivity region of the human eye and can therefore lead to visual discomfort.
3. The motor driving the Frame Saw must be correctly rated according to the manufacturer specification.
4. An undersized motor increases the flicker levels thereby increasing the K_{sm} factor.
5. A significant difference between load and no load flicker levels can be attributed to the mechanical variables of the Frame Saws as well as the mechanical properties of the timber.
6. The density and hardness for the different types of wood has an effect on the flicker levels.
7. Using the K_{sm} of 111 the maximum variation between the predicted and the measured flicker levels at a single sawmill plant was calculated as 43%.
8. The average variation between the predicted and measured flicker levels was calculated as 20%.
9. The empirical formula can be used to predict the flicker emission of the sawmill plants.

In conclusion it can be said that given all the mechanical variables associated with the Frame Saws and the impact of the density and hardness of the wood has on the flicker levels a K_{sm} factor of 111 can be used for flicker prediction purposes.

Chapter 7

7 Research Paper and Future Work

7.1 Research Paper

The author has prepared and presented a research paper at the 12th South African Universities Power Engineering Conference in January 2003 [8]. A copy of the paper is attached at the end of the thesis.

7.2 Future Work

1. A formula for the K_{sm} factor with its dependant variables (mechanical and wood density variables) needs to be devised so that more accuracy can put in place.

2. The K_{sm} factor of 111 needs to be applied to a sawmill site under development. Then once in operation flicker measurements can be conducted and the effectiveness of the developed flicker prediction methodology can be ascertained.

References

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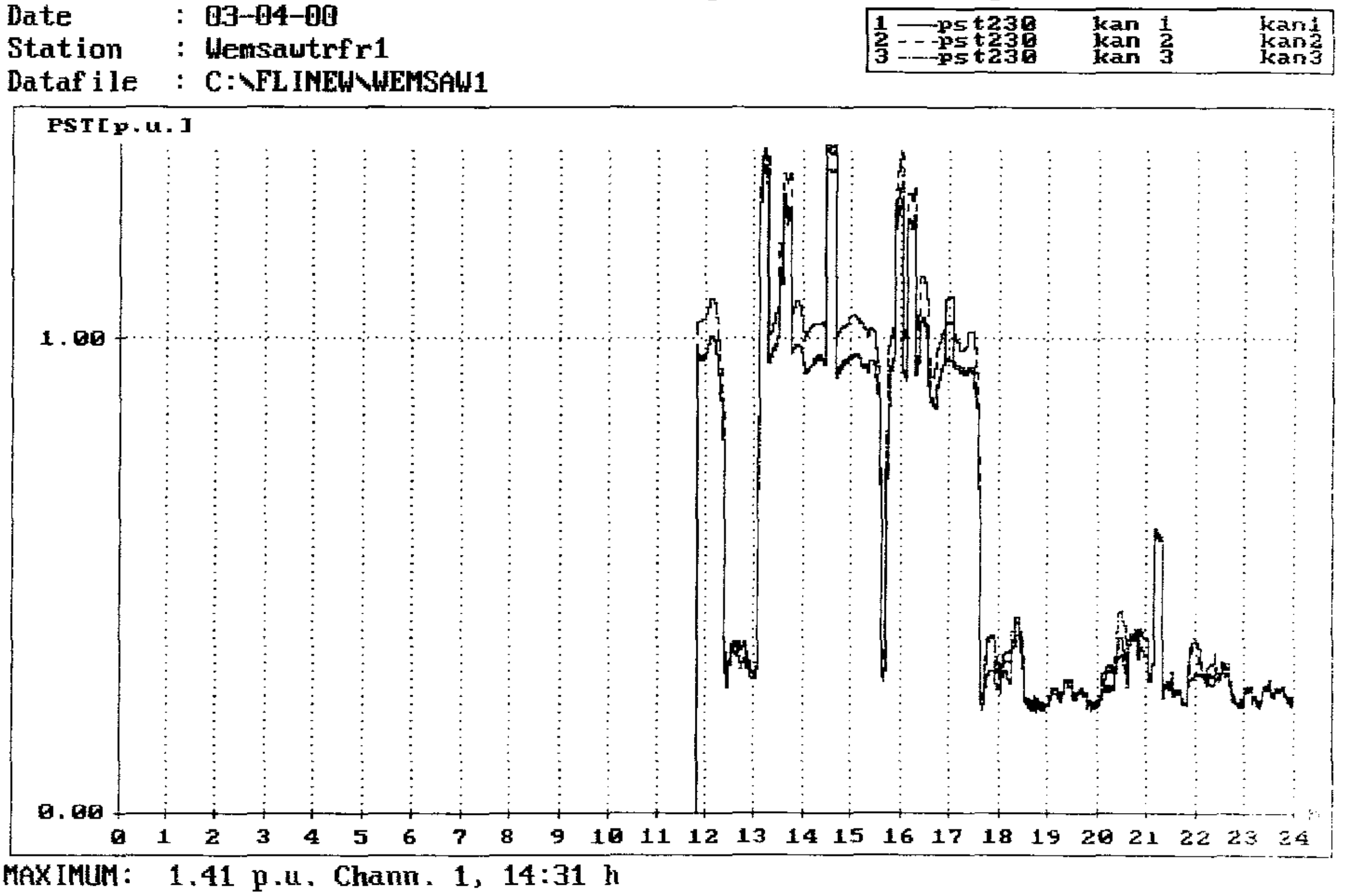
Appendix A DOS Based Flicker Graphs and Data

Digital Flickermeter — Day-Diagram — Sunday — 04/03/94

Date : 03-04-00

Station : Wemsautrfr1

Datafile : C:\FLINEW\WEMSAW1



MAXIMUM: 1.41 p.u. Chann. 1, 14:31 h

Date : 03/04/2000
Station : Wemsawtrfr1
Datafile : C:\FLICKER\WEMSAW1\WEMSAW1

CHANNEL-C(:

```
Channel  |                 1 |               2 |               3 |               4 |               5 |               6 |
         |kan              1 |kan            2 |kan            3 |kan            4 |kan            5 |kan            6 |
         |kan1     |kan2     |kan3    |kan4    |kan5    |kan6    |
-------------------------------------------------------------------------
Type     |FLI230   |FLI230   |FLI230  |        F(t)     |       F(t)      |       F(t)      |
-------------------------------------------------------------------------
Nominal  |                20 %|               20 %|               20 %|      nenn4|     nenn5|     nenn6|
Meas./V  |--4      V--|--4   V--|--4   V--|2.3000V|2.3000V|2.3000V|
```

Pst-Step : 1 min - 4 Buffers
Pst-Window : 10 min i.e. 10 Pst-Steps

	mm/dd/yy	hh:mm:ss	PST1	PST2	PST3	MIN4	AVR4	MAX4	MIN5	AVR5	MAX5	MIN6	AVR6
Su	04/03/1994	11:51:00	0.954	1.016	0.983	94.79024	96.48782	97.86854	95.85172	97.48152	98.93002	94.0472	95.99443
Su	04/03/1994	11:52:00	0.936	1.007	0.964	94.57794	96.40907	97.76239	95.74558	97.35344	98.82387	94.2595	95.94832
Su	04/03/1994	11:53:00	0.953	1.033	0.967	94.57794	96.31602	97.97469	95.32098	97.14661	98.82387	94.15335	95.89401
Su	04/03/1994	11:54:00	0.95	1.028	0.958	93.83491	96.19395	97.5501	95.00254	97.03651	98.50542	93.72876	95.72186
Su	04/03/1994	11:55:00	0.951	1.033	0.958	94.47179	96.19675	97.5501	95.42713	97.19188	98.61157	94.0472	95.78328
Su	04/03/1994	11:56:00	0.952	1.036	0.957	94.36565	95.97644	97.3378	95.21484	97.03719	98.71772	93.72876	95.5927
Su	04/03/1994	11:57:00	0.955	1.039	0.959	94.36565	96.19914	97.65624	95.42713	97.28161	98.71772	93.83491	95.76171
Su	04/03/1994	11:58:00	0.954	1.037	0.961	94.36565	96.10249	97.76239	95.32098	97.06555	98.93002	93.72876	95.69142
Su	04/03/1994	11:59:00	0.951	1.035	0.959	93.94106	95.97297	97.65624	95.00254	96.87999	98.61157	93.51646	95.51767
Su	04/03/1994	12:00:00	0.957	1.04	0.964	94.36565	96.1971	97.5501	95.74558	97.32976	98.93002	94.0472	95.75353
Su	04/03/1994	12:01:00	0.96	1.048	0.963	94.47179	96.20069	97.76239	95.21484	97.26083	98.82387	93.72876	95.75055
Su	04/03/1994	12:02:00	0.967	1.052	0.967	94.47179	96.28742	97.65624	95.10869	97.09046	98.71772	93.83491	95.80009
Su	04/03/1994	12:03:00	0.97	1.051	0.968	94.57794	96.22851	97.65624	95.21484	97.11876	98.71772	93.62261	95.71583
Su	04/03/1994	12:04:00	0.974	1.057	0.972	94.57794	96.47351	97.97469	95.32098	97.35437	98.93002	94.15335	95.95969
Su	04/03/1994	12:05:00	0.988	1.066	0.987	93.94106	96.67882	98.39928	95.21484	97.4397	99.03616	93.51646	96.16244

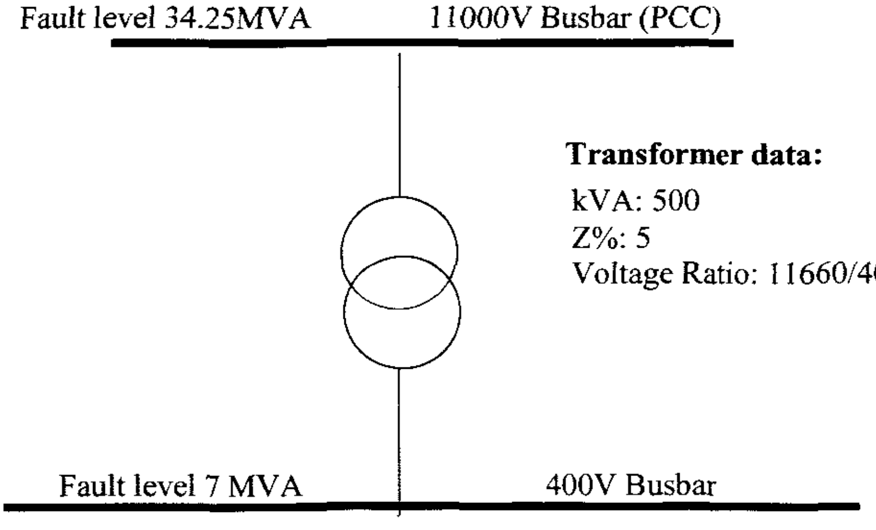
Su	04/03/1994	12:06:00	0.999	1.079	1.001	94.15335	96.15627	97.65624	95.10869	97.07443	98.61157	93.62261	95.65786
Su	04/03/1994	12:07:00	1	1.082	1.002	93.30417	96.0642	97.86854	93.83491	96.88553	98.50542	92.34884	95.55985
Su	04/03/1994	12:08:00	0.999	1.08	0.999	93.83491	96.16377	97.65624	94.89639	96.957	98.50542	93.62261	95.74318
Su	04/03/1994	12:09:00	1.003	1.083	1.001	94.47179	96.17753	97.5501	95.32098	97.03042	98.50542	93.94106	95.81854
Su	04/03/1994	12:10:00	0.999	1.08	0.998	94.57794	96.26531	97.65624	95.32098	97.09509	98.61157	94.0472	95.98235
Su	04/03/1994	12:11:00	0.999	1.077	0.997	94.2595	96.1451	97.76239	95.00254	96.85767	98.61157	93.83491	95.89523
Su	04/03/1994	12:12:00	0.996	1.074	0.995	94.47179	96.28044	98.08083	95.21484	97.0005	98.61157	94.2595	95.94754
Su	04/03/1994	12:13:00	0.991	1.071	0.991	94.47179	96.58035	98.18698	95.53328	97.43353	99.03616	94.36565	96.23035
Su	04/03/1994	12:14:00	0.99	1.066	0.991	94.89639	96.55051	98.08083	95.85172	97.38627	98.82387	94.15335	96.2767
Su	04/03/1994	12:15:00	0.964	1.044	0.967	95.32098	98.5163	100.4161	96.59476	99.61424	101.5837	95.21484	98.38097
Su	04/03/1994	12:16:00	0.945	1.018	0.942	97.3378	98.98546	100.4161	98.29313	100.1389	101.6899	97.23164	98.88295
Su	04/03/1994	12:17:00	0.927	0.995	0.923	97.1255	98.92985	100.3099	98.29313	100.0029	101.2653	97.01935	98.7808
Su	04/03/1994	12:18:00	0.918	0.985	0.913	97.1255	98.96269	100.5222	98.50542	100.0003	101.4776	96.9132	98.81415
Su	04/03/1994	12:19:00	0.897	0.964	0.894	97.3378	98.93012	100.3099	98.18698	99.9804	101.2653	97.23164	98.85184
Su	04/03/1994	12:20:00	0.872	0.933	0.87	97.23164	98.89426	100.4161	98.18698	99.83308	101.5837	97.01935	98.78412
Su	04/03/1994	12:21:00	0.84	0.898	0.84	97.3378	98.98806	100.3099	97.97469	99.9143	101.2653	97.01935	98.76938
Su	04/03/1994	12:22:00	0.787	0.844	0.787	97.3378	98.97941	100.3099	98.18698	99.90796	101.2653	97.1255	98.79561
Su	04/03/1994	12:23:00	0.674	0.713	0.68	97.44395	98.99883	100.4161	98.29313	99.88017	101.2653	97.01935	98.79871
Su	04/03/1994	12:24:00	0.404	0.412	0.424	97.44395	99.02152	100.4161	98.39928	99.96969	101.6899	97.3378	98.83008
Su	04/03/1994	12:25:00	0.312	0.295	0.336	97.01935	98.87522	100.3099	98.39928	100.0633	101.796	96.70091	98.76952
Su	04/03/1994	12:26:00	0.288	0.275	0.321	97.44395	99.14636	100.4161	98.71772	100.2764	101.5837	97.3378	98.99768
Su	04/03/1994	12:27:00	0.261	0.256	0.291	97.5501	99.24062	100.6284	98.82387	100.4356	101.6899	97.01935	99.08841
Su	04/03/1994	12:28:00	0.268	0.262	0.281	97.23164	99.16588	100.5222	98.50542	100.3805	101.796	97.01935	99.00501
Su	04/03/1994	12:29:00	0.298	0.298	0.312	97.3378	99.13606	100.4161	98.82387	100.523	101.9022	97.3378	99.0107
Su	04/03/1994	12:30:00	0.309	0.319	0.32	97.3378	98.93117	100.4161	98.82387	100.3597	101.9022	97.3378	98.9139
Su	04/03/1994	12:31:00	0.301	0.314	0.313	97.1255	99.11745	100.5222	99.03616	100.5915	102.1145	97.44395	99.13425
Su	04/03/1994	12:32:00	0.337	0.345	0.356	97.3378	99.12834	100.8407	98.61157	100.6714	102.1145	97.3378	99.07808
Su	04/03/1994	12:33:00	0.338	0.348	0.357	97.44395	99.13332	100.7345	99.03616	100.5627	102.0083	97.3378	99.07545
Su	04/03/1994	12:34:00	0.34	0.352	0.359	97.44395	99.07028	100.4161	99.03616	100.5698	101.9022	97.01935	99.0116
Su	04/03/1994	12:35:00	0.339	0.351	0.36	97.1255	99.07629	100.4161	98.71772	100.4207	102.0083	97.23164	99.01489
Su	04/03/1994	12:36:00	0.339	0.352	0.36	97.5501	99.19444	100.8407	98.61157	100.3193	101.796	97.5501	99.13297
Su	04/03/1994	12:37:00	0.339	0.351	0.36	97.76239	99.32204	100.6284	98.61157	100.3066	101.5837	97.65624	99.34792
Su	04/03/1994	12:38:00	0.332	0.349	0.356	97.76239	99.34191	100.8407	98.82387	100.3782	101.6899	97.5501	99.35958
Su	04/03/1994	12:39:00	0.32	0.334	0.342	97.5501	99.21252	100.7345	98.61157	100.2827	101.796	97.3378	99.18689
Su	04/03/1994	12:40:00	0.342	0.326	0.342	97.44395	99.17313	100.7345	98.71772	100.2258	101.796	97.3378	99.1384
Su	04/03/1994	12:41:00	0.357	0.329	0.356	97.5501	99.15015	100.5222	98.29313	100.2017	101.6899	97.3378	99.10956

Su	04/03/1994	12:42:00	0.34	0.301	0.331	97.44395	99.13178	100.5222	98.39928	100.1069	101.3714	97.3378	99.06579
Su	04/03/1994	12:43:00	0.343	0.301	0.341	97.65624	99.23306	100.8407	98.61157	100.2471	101.5837	97.5501	99.22292
Su	04/03/1994	12:44:00	0.341	0.294	0.335	97.5501	99.29378	101.053	98.71772	100.313	101.5837	97.76239	99.30747
Su	04/03/1994	12:45:00	0.349	0.314	0.352	97.01935	98.88305	100.7345	97.76239	99.8733	101.6899	96.70091	98.89694
Su	04/03/1994	12:46:00	0.349	0.315	0.352	96.70091	98.44072	99.7792	97.86854	99.57777	100.9468	96.80705	98.44457
Su	04/03/1994	12:47:00	0.351	0.32	0.354	96.80705	98.43692	99.67305	97.86854	99.56452	100.9468	96.9132	98.46914
Su	04/03/1994	12:48:00	0.354	0.326	0.359	96.59476	98.37822	99.88535	97.76239	99.39778	100.7345	96.70091	98.41117
Su	04/03/1994	12:49:00	0.346	0.316	0.349	96.70091	98.44791	99.67305	97.97469	99.46835	101.053	96.80705	98.46272
Su	04/03/1994	12:50:00	0.316	0.304	0.336	96.9132	98.36227	99.7792	97.65624	99.39206	100.9468	96.70091	98.37369
Su	04/03/1994	12:51:00	0.326	0.301	0.322	96.70091	98.3794	99.67305	97.5501	99.32938	100.6284	96.38246	98.3593
Su	04/03/1994	12:52:00	0.322	0.305	0.318	96.80705	98.30953	99.67305	97.5501	99.40031	101.053	96.70091	98.2874
Su	04/03/1994	12:53:00	0.318	0.301	0.308	96.38246	98.32285	99.88535	97.76239	99.4008	100.8407	96.59476	98.27633
Su	04/03/1994	12:54:00	0.32	0.302	0.309	96.9132	98.5331	99.88535	97.86854	99.5549	100.9468	96.70091	98.50816
Su	04/03/1994	12:55:00	0.296	0.285	0.293	96.27631	98.26888	99.67305	97.76239	99.33471	101.053	96.17017	98.26772
Su	04/03/1994	12:56:00	0.299	0.287	0.295	96.70091	98.42408	99.9915	97.5501	99.48726	101.1591	96.70091	98.42908
Su	04/03/1994	12:57:00	0.296	0.282	0.291	96.48861	98.40707	99.67305	97.97469	99.54865	100.8407	96.70091	98.40148
Su	04/03/1994	12:58:00	0.296	0.282	0.295	96.48861	98.42169	99.7792	97.86854	99.54633	101.2653	96.59476	98.44518
Su	04/03/1994	12:59:00	0.299	0.285	0.297	96.48861	98.24722	99.88535	97.65624	99.48757	100.8407	96.48861	98.26945
Su	04/03/1994	13:00:00	0.3	0.285	0.297	96.80705	98.55143	100.0976	98.29313	99.95455	101.3714	96.48861	98.56364
Su	04/03/1994	13:01:00	0.277	0.281	0.292	96.9132	98.58418	99.88535	98.39928	99.97527	101.2653	96.70091	98.55045
Su	04/03/1994	13:02:00	0.28	0.282	0.29	96.27631	98.45273	99.67305	98.18698	99.85251	101.2653	96.38246	98.44292
Su	04/03/1994	13:03:00	0.286	0.289	0.296	96.80705	98.58749	100.0976	98.39928	100.0587	101.2653	96.80705	98.58184
Su	04/03/1994	13:04:00	0.302	0.303	0.316	96.38246	98.42996	99.7792	97.97469	99.93651	101.3714	96.38246	98.41383
Su	04/03/1994	13:05:00	0.462	0.482	0.47	94.89639	97.728	100.3099	96.59476	99.25073	101.3714	95.00254	97.74759
Su	04/03/1994	13:06:00	0.6	0.628	0.643	94.47179	97.21431	98.71772	95.53328	98.7142	100.2038	94.89639	97.24807
Su	04/03/1994	13:07:00	0.833	0.829	0.682	94.47179	97.10689	98.71772	96.17017	98.47382	99.88535	94.36565	97.12201
Su	04/03/1994	13:08:00	1.215	1.226	1.241	91.6058	95.46071	97.86854	92.77343	96.59212	99.14231	91.71195	95.32534
Su	04/03/1994	13:09:00	1.286	1.307	1.317	94.0472	95.6717	97.3378	95.10869	96.73631	98.18698	93.51646	95.5251
Su	04/03/1994	13:10:00	1.319	1.345	1.35	93.72876	95.49622	97.01935	94.89639	96.63997	98.18698	93.30417	95.30237
Su	04/03/1994	13:11:00	1.336	1.364	1.364	93.72876	95.49262	97.1255	94.57794	96.84216	98.18698	93.09187	95.31593
Su	04/03/1994	13:12:00	1.35	1.381	1.377	93.83491	95.58281	97.23164	95.00254	96.71349	97.97469	93.51646	95.42304
Su	04/03/1994	13:13:00	1.357	1.391	1.385	93.72876	95.61533	97.01935	95.10869	96.73885	98.29313	93.62261	95.45951
Su	04/03/1994	13:14:00	1.364	1.399	1.391	93.62261	95.45151	97.01935	94.79024	96.70325	98.08083	93.51646	95.30484
Su	04/03/1994	13:15:00	1.365	1.4	1.389	93.51646	95.48238	97.01935	94.68409	96.69986	98.18698	93.30417	95.33394
Su	04/03/1994	13:16:00	1.356	1.384	1.325	94.15335	95.80326	97.1255	95.32098	97.05133	98.61157	94.0472	95.67459
Su	04/03/1994	13:17:00	1.31	1.379	1.327	94.0472	95.71528	97.01935	95.32098	97.04462	98.61157	93.72876	95.54359

Su	04/03/1994	13:18:00	0.951	1.008	0.962	93.94106	95.62557	97.23164	95.10869	96.89544	98.50542	93.72876	95.44684
Su	04/03/1994	13:19:00	0.949	1.007	0.956	93.94106	95.68654	97.3378	94.79024	96.82165	98.71772	93.72876	95.50877
Su	04/03/1994	13:20:00	0.946	1.004	0.951	93.62261	95.76762	97.3378	94.79024	96.84827	98.29313	93.51646	95.59792
Su	04/03/1994	13:21:00	0.95	1.007	0.96	94.36565	95.98444	97.44395	95.63943	97.26224	98.82387	94.0472	95.83115
Su	04/03/1994	13:22:00	0.959	1.012	0.965	94.15335	95.94265	97.3378	95.74558	97.3385	98.82387	93.72876	95.81419
Su	04/03/1994	13:23:00	0.964	1.017	0.969	93.72876	95.53668	97.23164	94.79024	96.79886	98.29313	93.19802	95.37228
Su	04/03/1994	13:24:00	0.966	1.021	0.971	93.51646	95.44824	97.01935	94.79024	96.50495	98.29313	93.30417	95.30588
Su	04/03/1994	13:25:00	0.974	1.031	0.978	93.94106	95.49852	97.01935	94.89639	96.49918	97.97469	93.72876	95.37254
Su	04/03/1994	13:26:00	0.98	1.039	0.98	93.62261	95.44833	96.9132	94.79024	96.42503	97.76239	93.30417	95.33055
Su	04/03/1994	13:27:00	0.987	1.051	0.984	93.51646	95.32005	96.80705	94.57794	96.43543	97.97469	93.19802	95.19569
Su	04/03/1994	13:28:00	0.988	1.055	0.986	93.72876	95.39553	97.01935	94.79024	96.46448	97.97469	93.09187	95.25905
Su	04/03/1994	13:29:00	0.996	1.064	0.995	93.62261	95.37521	96.9132	94.79024	96.49362	97.86854	93.30417	95.24771
Su	04/03/1994	13:30:00	1.002	1.066	1.001	93.83491	95.85921	97.76239	95.21484	97.23855	99.14231	93.30417	95.79752
Su	04/03/1994	13:31:00	1.137	1.199	1.15	92.56113	96.45426	97.86854	94.0472	97.95355	99.35461	92.34884	96.40743
Su	04/03/1994	13:32:00	1.127	1.19	1.14	94.89639	96.59432	97.97469	96.38246	98.09592	99.5669	94.47179	96.54892
Su	04/03/1994	13:33:00	1.12	1.183	1.134	94.89639	96.62545	97.97469	96.48861	98.14507	99.46075	94.68409	96.59682
Su	04/03/1994	13:34:00	1.111	1.173	1.124	94.79024	96.5881	97.97469	96.17017	97.93027	99.35461	94.47179	96.55663
Su	04/03/1994	13:35:00	1.096	1.157	1.11	94.79024	96.47351	97.86854	95.95787	97.79009	99.14231	94.79024	96.45011
Su	04/03/1994	13:36:00	1.283	1.35	1.303	91.81809	95.55038	97.65624	93.09187	96.7987	99.03616	91.6058	95.44733
Su	04/03/1994	13:37:00	1.273	1.339	1.295	93.94106	95.49121	97.1255	95.21484	96.71039	98.18698	93.62261	95.38025
Su	04/03/1994	13:38:00	1.267	1.336	1.287	93.62261	95.3956	96.80705	94.79024	96.6098	97.97469	93.41032	95.26816
Su	04/03/1994	13:39:00	1.258	1.328	1.277	93.62261	95.34874	96.9132	94.79024	96.58922	97.97469	93.51646	95.19511
Su	04/03/1994	13:40:00	1.257	1.334	1.275	93.62261	95.38427	96.9132	94.89639	96.62654	97.97469	93.19802	95.22321
Su	04/03/1994	13:41:00	1.228	1.313	1.238	93.41032	95.15656	96.70091	94.79024	96.38009	97.86854	93.09187	94.96281
Su	04/03/1994	13:42:00	1.239	1.325	1.247	93.41032	95.22618	96.70091	94.79024	96.48003	98.08083	93.30417	95.02229
Su	04/03/1994	13:43:00	1.25	1.335	1.258	93.72876	95.54439	97.1255	95.10869	96.77397	98.18698	93.62261	95.3573
Su	04/03/1994	13:44:00	1.259	1.344	1.266	93.62261	95.43107	97.01935	95.00254	96.66386	98.08083	93.51646	95.24204
Su	04/03/1994	13:45:00	1.265	1.35	1.273	93.51646	95.33026	97.01935	94.89639	96.63019	98.18698	92.87958	95.18884
Su	04/03/1994	13:46:00	0.961	1.045	0.962	93.19802	94.97449	96.48861	94.36565	96.21414	97.86854	92.77343	94.81716
Su	04/03/1994	13:47:00	0.964	1.048	0.965	93.62261	95.25043	96.48861	94.79024	96.48269	97.97469	93.30417	95.09728
Su	04/03/1994	13:48:00	0.967	1.052	0.967	93.41032	95.11663	96.70091	94.68409	96.36358	97.76239	93.30417	95.00192
Su	04/03/1994	13:49:00	0.975	1.064	0.974	93.41032	95.04643	96.48861	94.57794	96.2601	97.65624	93.19802	94.94989
Su	04/03/1994	13:50:00	0.978	1.066	0.977	92.34884	95.2362	96.9132	93.62261	96.38922	97.97469	92.56113	95.13872
Su	04/03/1994	13:51:00	0.984	1.073	0.978	93.51646	95.3044	96.9132	94.57794	96.3786	97.76239	93.51646	95.21115
Su	04/03/1994	13:52:00	0.988	1.077	0.982	93.72876	95.61208	97.3378	95.00254	96.70946	98.29313	93.72876	95.47015
Su	04/03/1994	13:53:00	0.988	1.078	0.981	93.94106	95.58471	97.1255	95.00254	96.66391	98.18698	93.72876	95.49297

Appendix B- Typical Fault Calculations at point of Measuring

The three phase fault level on the 11000V busbar is available from the utilities planning department. A typical electrical layout is shown with the relevant transformer information. To calculate the fault level in MVA on the 400V busbar the following method was used:



$$V_b = 400V = 1pu$$

$$S_b = 34.25MVA$$

$$\text{3ph fault level on 11000V busbar} = 1.8kA$$

$$= 34.25MVA$$

$$Z_{pu} = 0.05$$

$$\therefore$$

$$Z_{PU\ new} = Z_{PU\ old} \times \frac{MVA_{new}}{MVA_{old}} \times \left(\frac{V_{old}}{V_{new}}\right)^2$$

$$= 0.05 \times \frac{\sqrt{3} \times 11 \times 10^3 \times 1.8 \times 10^3}{500 \times 10^3} \times \left(\frac{11660}{11000}\right)^2$$

$$= 3.85$$

$$Z_b = \frac{V_b^2}{S_b} = \frac{(11000)^2}{34.25x10^3} = 3.532\Omega$$

$$Z_{source} = \frac{11000/\sqrt{3}}{1.8x10^3} = 3.532\Omega$$

$$Z_{pu\ source} = \frac{3.532}{3.532} = 1$$

$$\text{Assuming negligible Resistance:}$$

$$Z_{totalpu} = Z_{source} + Z_{trfr}$$

$$= 1 + 3.85$$

$$= 4.85$$

$\therefore$

$$I_{pu} = \frac{V_b}{Z_{pu}}$$

$$I_{pu} = \frac{1}{4.85}$$

$$= 0.206\text{A pu}$$

$$I_{base} = \frac{S_b}{\sqrt{3} \times V_b}$$

$$= \frac{34.25 \times 10^6}{\sqrt{3} \times 400}$$

$$= 49.5\text{kA}$$

$\therefore$

$$I_{pu} = \frac{I_a}{I_b}$$

$\therefore$

$$I_{a\ fault} = I_b \times I_{pu}$$

$$= 49.5 \times 10^3 \times 0.206$$

$$= 10.19\text{kA}$$

$\therefore$

$$\text{MVA} = \sqrt{3} \times V \times I_a$$

$$= 1.73 \times 400 \times 10.19$$

$$= 7.05\text{MVA}$$

INVESTIGATING FLICKER PREDICTION TECHNIQUES FOR SAWMILLS

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Abstract. No procedure exists to predict the flicker emission level for sawmills. An empirical formula is used to calculate K_{sm} factors for frame saws at sawmill plants. This paper investigates the accuracy of the K_{sm} factors. Flicker measurements have been conducted at different sawmills and their K_{sm} factors were calculated. This will help the utility to predict the flicker emission on the network and ensure future compliance to standards. The results are compared and conclusions are drawn.

Key Words. Flicker emission; K_{sm} factor; empirical formula.

1. INTRODUCTION

Flicker occurs when variable loads, such as arc furnaces, crusher and sawmill plants operate in a power system. These loads cause the supply voltage to fluctuate. The visual perception in luminance in lighting equipment is due to the voltage fluctuation and therefore, called flicker. The human eye is sensitive to voltage fluctuations, as small from 0.3% - 0.5% in the frequency range 8 – 10Hz. [1]

Voltage fluctuations are caused by variable currents drawn by variable loads, and the supply impedance of the power system, as illustrated by Fig. 1. [1]

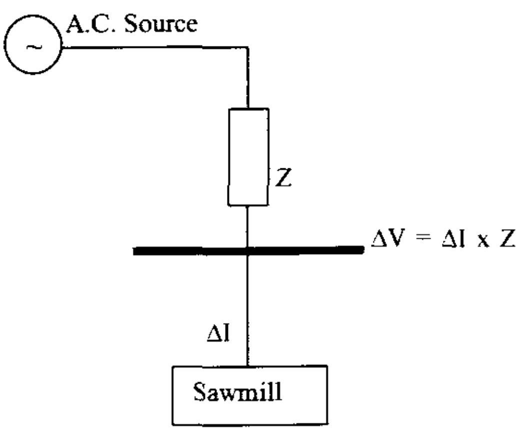

Fig. 1: Voltage Variation Caused by Variable Load

Flicker is evaluated in terms of P_{st} (short term flicker severity). The threshold at which the flicker becomes perceptible to the human eye is evaluated at $P_{st} = 1$. [2]

The increased use of varying loads, such as arc furnaces, crushers and sawmills has generated the need for improved techniques to predict the flicker emitted by these loads on the power system. Utilities must comply with NRS 048-2 standards in terms of flicker levels. [3] A utility therefore needs to predict the flicker emission of these loads on a power system to ensure future compliance to standards.
Standard flicker curves are depicted in IEC 1000-3-7. [4] Due to varying loads the voltage fluctuations are erratic, therefore, the associated flicker levels cannot be predicted by these standard curves.

A possible solution lies in the use of an empirical formula:

$$P_{st} = \frac{K_{sm} \times \text{Load size (VA)}}{\text{Fault level (VA)}} \qquad (1)$$

where: K_{sm} = electrical behaviour of the motor

This formula accuracy has been proven to be reasonably effective on crusher plants. [5]

The objective of this paper is to calculate a K_{sm} factor that can be used with the empirical formula to predict the flicker emitted by frame saws. This paper therefore investigates the application of the empirical formula at sawmill plants and is used to calculate the K_{sm} factors. The K_{sm} (characteristic coefficient) for sawmills refers to the electrical behaviour of the motor when exposed to the sawing process. This prediction technique, utilities can use to ensure that new customers operating with variable loads do not exceed flicker limits. When two frame saws are fed from the same supply and their flicker is measured individually, their total flicker can be predicted using the "Cubic Summation Law" from IEC 1000-3-7 standard. The "Cubic Summation Law" is given by the formula; [4]

$$P_{st} = \sqrt[3]{P_{st}(load1)^3 + P_{st}(load2)^3 + ...P_{st}(loadn)^3} \qquad (2)$$

2. REFERENCE SITE

K_{sm} factors have been calculated for frame saws at a sawmill site, in a previous investigation and are tabulated in Table 1. [6]
These results will be used as a reference and will be compared to other investigations.

Table 1: Reference site Ksm Factors

Load	K_{sm} Factor
Frame saw 1	51
Frame saw 2	40

3. METHODOLOGY

The following methodology is used to conduct this research:

- Measure the flicker levels at sawmill plants.
- With the use of the empirical formula calculate the K_{sm} factors.
- Compare the accuracy of the K_{sm} factors to the previously calculated values determined at the reference site.

4. FRAME SAW LAYOUT

Frame saws, also known as Gang saws, (model USV 71/56), cut logs with a maximum diameter of 530mm and a maximum length of 6.3m. At various plants, different motor sizes are used to drive the frame saws flywheels, by use of vee-belts. These flywheels vary in diameter size at the different plants. The flywheels are directly connected to the frame in which the blades are installed.

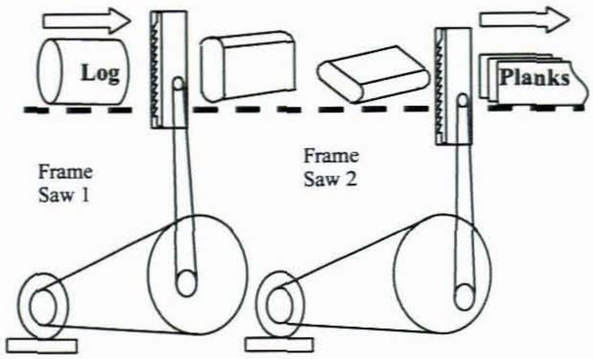

Fig. 2: Sawing Process of Frame Saws

A frame saw production line typically consists of two saws in series. The operation of the two frame saws is similar. The first frame saw (Log Frame) does the primary sawing which involves the raw logs being cut to remove the bark. Frame saw two (Deal Frame) is used for the secondary sawing which involves the cutting of the rest of the logs into thinner beams that makes the final product, which are planks as shown in Fig. 2.

5. MEASUREMENTS AND ANALYSIS

Measurements were done at the other sawmills to determine the accuracy of the empirical formula and K_{sm} factor for frame saws.

5.1 Sawmill A

The electrical layout for this plant is shown in Fig. 3. The flicker meter (FM) and the voltage recorder (VR) were connected to the 400V secondary side of the transformer. The total flicker level was measured. The voltage recorder was used to ensure that the assessed flicker levels were not caused by dips on the supply network.

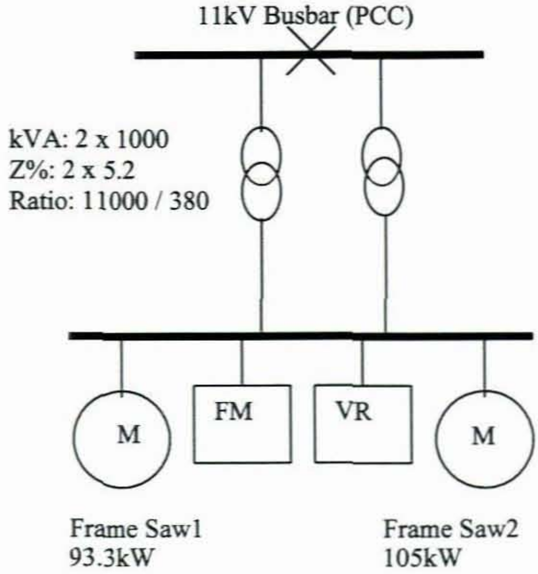

Fig. 3: Single Line Diagram of Sawmill A

Sawmill A consisted of two frame saws operating in series. Frame saw 1 is driven by a 93.3kW motor and frame saw 2 by a 105kW motor. Both saws were in operation and the total flicker was measured as shown in Fig. 4.

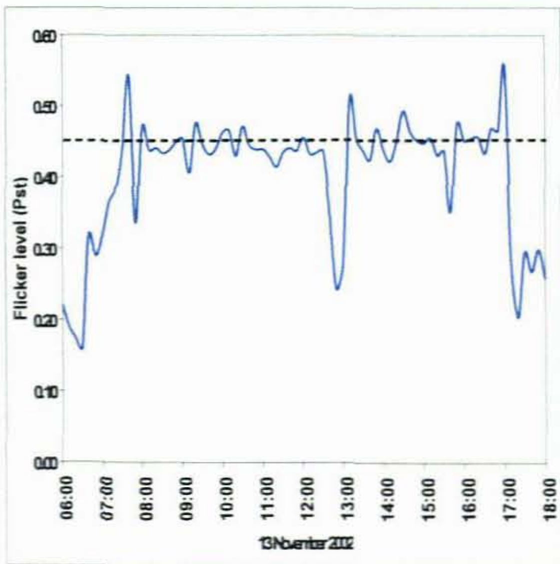

Fig. 4: Total flicker measured for both Frame Saws

Each frame saw was run individually to determine their flicker emission level contributions. To verify the total flicker that was measured, equation 2 can be used.

$$Pst = \sqrt[3]{(0.35)^3 + (0.33)^3}$$

$P_{st} = 0.43$

The total flicker calculated $P_{st} = 0.43$ is representative of the total flicker measured as shown in Fig. 4.

Flywheel dimensions and speeds were also taken for each frame saw. The fault levels were calculated for the busbars where measurements were performed. The results are tabulated in Table 2.

Table 2: Results for Sawmill A

Site	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø(m)	LV Fault level (MVA)	Pst	Ksm
Site A	Frame Saw1	93.3	312	1.5	26.4	0.35	100
	Frame Saw2	105	320	1.35	26.4	0.33	83

5.2 Sawmill B

The electrical layout for this plant is shown in Fig. 5. The flicker meter (FM) and the voltage recorder (VR) were connected on the 400V secondary side of the transformer. The total flicker level was measured on the 400V busbar.

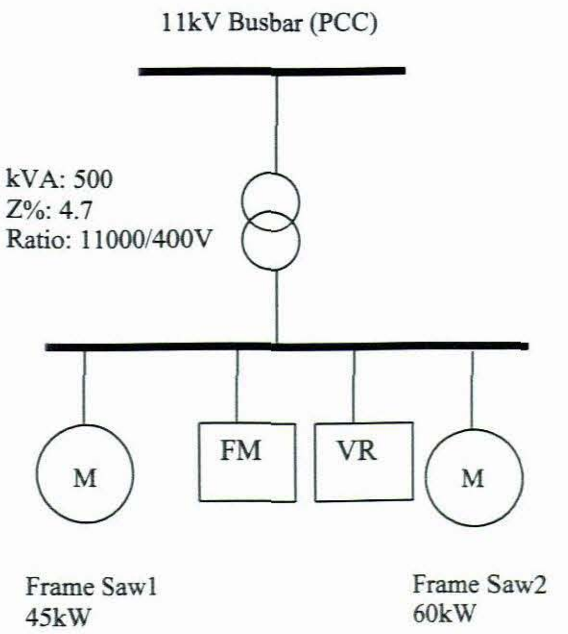

Fig. 5: Single Line diagram of Sawmill B

Sawmill B consisted of two frame saws in series. Frame Saw 1 is driven by a 45kW motor and frame saw 2 by a 60kW motor. As illustrated in figure 6, frame saw 1 assessed flicker level is a P_{st} = 0.58 (point A) and for frame saw 2 P_{st} = 0.33 (point B). The total flicker P_{st} = 0.62 (point C).

To verify the total flicker that was measured, equation 2 can be used.

$$Pst = \sqrt[3]{(0.58)^3 + (0.33)^3}$$

$P_{st} = 0.62$

The total flicker calculated P_{st} = 0.62 is representative of the total flicker measured as shown in Fig. 6.

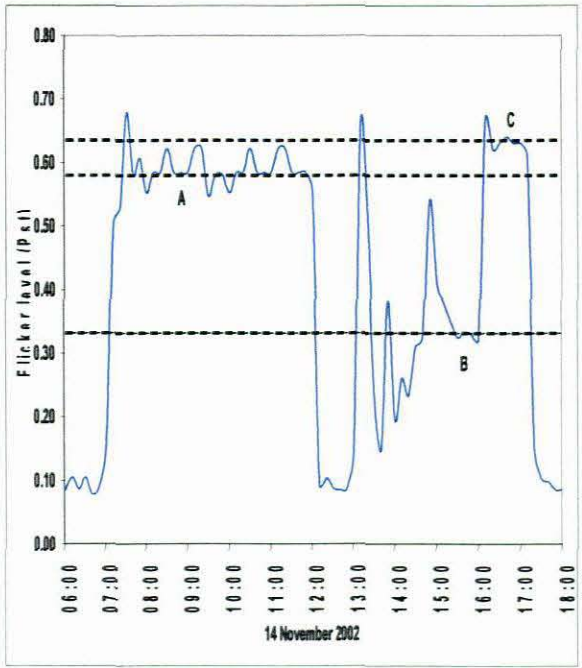

Fig. 6: Individual Flicker and Total flicker

K_{sm} Factors were calculated for the respective saws. The results are tabulated in Table 3.

Table 3: Results for Sawmill B

Site	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø(m)	LV Fault level (MVA)	Pst	Ksm
Site B	Frame Saw 1	45	251	1.24	8.9	0.58	114
	Frame Saw 2	60	296	1.2	8.9	0.33	49

5.3 Sawmill C

The electrical layout for this plant is shown in Fig. 7. The flicker meter (FM) and the voltage recorder (VR) were connected on the 400V secondary side of the transformer. The total flicker level was measured on the 400V busbar.

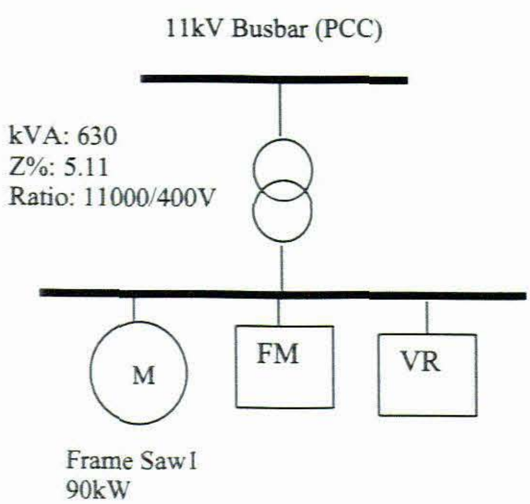

Fig. 7: Single Line Diagram of Sawmill C

Sawmill C consisted of one frame saw only. This frame saw is driven by a 90kW motor. The flicker level for this frame saw was measured as shown in Fig. 8.

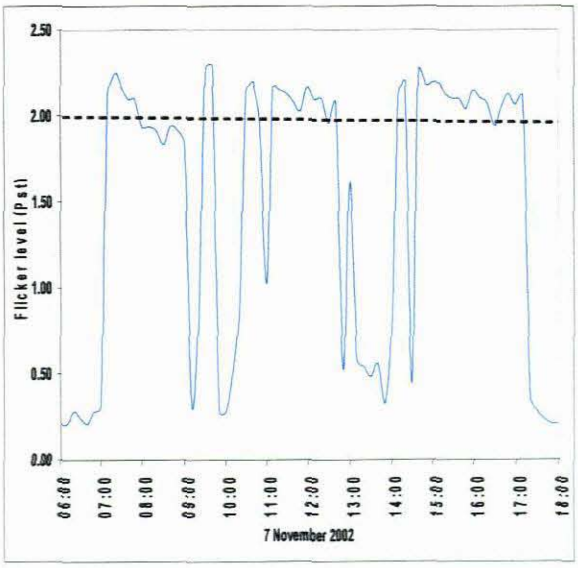

Fig. 8: Total flicker for Frame Saw 1

The results for Sawmill C are tabulated in Table 4.

Table 4: Results for Sawmill C

Site	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø(m)	LV Fault level (MVA)	Pst	Ksm
Site C	Frame Saw 1	90	303	1.2	6.3	2.00	139

6. COMPARATIVE RESULTS

Table 5 shows a comparison of results compared each site to the reference site. As the mechanical operation, is the same, the flicker levels of frame saw 1 and 2 should be similar. This is not the case at each site. At each site, frame saw1 and 2 K_{sm} factors were compared to the reference site. At site A frame saw 1 and 2 K_{sm} factors are almost double that of the reference site. At site B and C, frame saw 1 K_{sm} factors are more than double that of the reference site. Frame saw 2 K_{sm} factor for site B is almost the same as the reference site. According to the manual of these machines the rated size motors should be in the range of 90 to 110kW. According to this, site B has two undersized motors.

The reasons for the different K_{sm} factors could be due to the mechanical variables concerning the frame saws i.e. The direct and indirect method of connection from the motor to the flywheels, different size flywheels, different tensioning on vee-belts, different counter weights on flywheels and also different flywheel speeds. It could also be due to the different method of feed being uniform or variable feed. [7]

Table 5: Summary of comparative results

Site	Load	Motor size (kW)	Fly wheel speed (rpm)	Fly wheel Ø (m)	LV Fault level (MVA)	Pst	Ksm
Reference site	Frame Saw1	132	306	1.35	7.0	0.97	51
	Frame Saw2	132	328	1.35	7.0	0.75	40
Site A	Frame Saw1	93.3	312	1.5	26.4	0.35	100
	Frame Saw2	105	320	1.35	26.4	0.33	83
Site B	Frame Saw1	45	251	1.24	8.9	0.58	114
	Frame Saw2	60	296	1.2	8.9	0.33	49
Site C	Frame Saw1	90	303	1.2	6.3	2.00	139

7. CONCLUSIONS

a. Flicker levels for the two frame saws are found to be different at all sites.
b. K_{sm} factors are found to be inconsistent, however two groups are evident i.e. (40,49,51) and (83,114,139).
c. Further research is required to fully understand the mechanical behaviour of the frame saws and the impact on the K_{sm} factors.

ACKNOWLEDGEMENTS

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