The effect of controlling main ventilation fan inlet guide vanes for a deep level platinum mine to reduce electrical costs

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It all starts here ™

ABSTRACT

Title:	The effect of controlling main ventilation fan inlet guide vanes for a deep level platinum mine to reduce electrical costs
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Because of the annual electricity increases from Eskom that are above inflation, and the mining industry that is struggling to survive due to continuous increase in operating cost, the low selling price of precious metals, and past industrial action that took place, there is a need to investigate energy efficiency as well as demand side management methods to reduce the total electricity cost of end users. This can be achieved at a lower cost and in shorter periods of time than the construction of new power stations. In the past there have been many successful demand side management, as well as energy efficiency interventions, specifically in the mining industry.

The mining industry in South Africa currently consumes about 14% of the generated electricity and the ventilation usage on deep level mines consumes about 12% of this total. Electricity cost reductions on the ventilation load of a mine are thus important as not many studies have been done on them. However, since safety is of paramount importance on a mine, operational management is reluctant to investigate cost saving methods as it could compromise the environmental underground conditions and hence worker safety. Therefore utmost care should be taken when implementing energy efficiency or demand side management measures.

This study focuses on the effect of electricity costs for controlling the main ventilation fans inlet guide vanes of a deep level platinum mine. An actual mine was identified and used for the case study, which demonstrated the impact on costs without affecting the day to day mining operations which were at all times consistent with the environmental standards and regulations of the mine.

An actual reduction in power of 13.4% was demonstrated, which would result in an annual cost reduction of about R 1 600 000. With a capital investment cost of R 960 000 and an annual operational cost of R 120 000, a simple payback period of less than a year is achievable. This is expensive but could assist in the survival of the deep level mining industry, specifically the platinum mining industry.

SAMEVATTING

Title:	The effect of controlling main ventilation fan inlet guide vanes for a deep level platinum mine to reduce electrical costs
Outeur:	Cornelius J.P. Venter
Studieleier:	W.C. Kukard
Universiteit:	North-West University, Potchefstroom Campus
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Sleutel woorde:	Hoof waaiers, Inlaat lei wieke, elektriese koste besparing, energie effektiewe

As gevolg van die jaarlikse elektrisiteitsverhogings van Eskom wat hoër is as inflasie, en die mynbou industrie wat swaarkry as gevolg van deurlopende verhogings in bedryfs kostes, die laë verkoopsprys van edel metale, en industriële aksie wat plaasgevind het in die verlede, is dit nodig om energie effektiwiteit sowel as aanvraag bestuur metodes te ondersoek om die totale elektrisiteits kostes van eind gebruikers te verlaag. Dit kan bereik word teen ‘n laër koste en in korter periodes van tyd as die bou van nuwe krag stasies. In die verlede was daar vele suksesvolle aanvraags bestuur sowel as energie effektiewe ingrypings, spesifiek in die mynbou industrie.

Die mynbou industrie in Suid Afrika verbruik tans sowat 14% van die gegenereerde elektrisiteit en die ventilasie verbruik van diep vlak myne verbruik sowat 12% van die totaal. Elektrisiteits koste vermindering op die ventilasie las van ‘n myn is dus belangrik as gevolg van min studies wat al op die las gedoen is. Omdat veiligheid egter van kardinale belang op ‘n myn is, is operationele bestuur huiwerig om koste besparings geleenthede te ondersoek om rede dit die ondergrondse omgewings kondisies kan beinvloed en dus die die veiligheid van werkers. Daarom moet uiterste sorg geneem word wanneer die uitvoering van energie doeltreffendheid of vraagkant bestuur toegepas word.

Hierdie studie fokus op die uitwerking op die koste van elektrisiteit van die beheer van die hoof ventilasie waaiers se inlaat lei wieke van 'n diep vlak platinummyn. ‘n werklike myn was geïdentifiseer en word gebruik vir die gevallestudie, wat die impak op die koste toon sonder dat die dag-tot-dag mynbedrywighede wat te alle tye in ooreenstemming met die standaarde en regulasies van die myn omgewing was.

'n werklike afname in krag van 13,4% word getoon, wat sal lei tot 'n jaarlikse koste vermindering van ongeveer R 1 600 000. Met 'n kapitale belegging koste van R 960 000 en 'n jaarlikse operasionele koste van R 120 000, is 'n eenvoudige terugbetaling tydperk van minder as 'n jaar haalbaar. Dit is duur, maar kan help met die voortbestaan van die diep vlak mynbedryf, spesifiek die platinum mynbedryf.

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NOMENCLATURE

°C	Degree Celsius
A	Amperes
c/kWh	Cent per kilowatt hour
DB	Dry Bulb
DSM	Demand side management
EE	Energy efficiency
GW	Gigawatt
GWh	Gigawatt hours
IDM	Integrated Demand management
IGV	Inlet Guide Vanes
Kg/s	kilograms per second
kPa	kilo Pascal
kV	kilo volts
kW	Kilowatt
LF	Load factor
LM	Load Management
m	meter
m/s	meters per second
m^3/s	Cubic meters per second
mA	Milliamps
MF	Megaflex
MVF	Main Ventilation Fans
MW	Megawatt
Pa	Pascals
PLC	Programmable logic controller
R/kWh	Rand per kilowatt hour
R/MW	Rand per megawatt
rpm	revolutions per minute
SCADA	Supervisory control and data acquisition
V	Volts
VSD	Variable Speed Drive
WB	Wet Bulb

LIST OF SYMBOLS

m^2	Square meter
kg/m^3	kilogram per cubic meter
P_d	Air density of the drift
B_p	Barometric pressure
P_s	Measured static pressure
T_d	Drift temperature
P_{sc}	Corrected static pressure
P_{fc}	Air density of the drift
P_V	Average velocity pressure
n	Number of velocity pressure measurements
x_i	Value of each individual velocity pressure measurement
V_p	Average velocity
r	Resistance of the mine
Q	Average volume flow
A_d	Area of drift
P	Pressure
P_A	Air power of the fan
P_E	Electrical power of the fan
η	Efficiency
E	Electrical Energy

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CHAPTER 1 – INTRODUCTION

This chapter provides a brief background and the need for the study. The problem statement and objectives are also provided. This chapter concludes with a layout for the rest of the dissertation.

1.1 BACKGROUND

Due to the significant rising cost of electricity in the past couple of years in South Africa the need exists for the continuous research and development of load management (LM) and energy efficiency (EE) strategies. With the platinum mining industry being a mayor electricity consumer within South Africa and the platinum industry currently struggling to survive due to the low price of platinum and their high operational cost, the need arises to reduce the electricity cost of the mine. This could have a major impact on the total operating cost of the mine and therefore making the operations more feasible.

Managing energy efficiently to reduce electricity cost is therefore a critical element in the deep level mining industry. Unfortunately there is currently a low awareness of possible cost reduction strategies on the main ventilation system of deep level mines and therefore this study will focus specifically on the effect of controlling main ventilation fans (MVF) inlet guide vanes (IGVs) of a deep level platinum mine to reduce electrical costs.

The total volume of air that will be delivered to the underground working areas will be influenced by controlling the IGVs on the MVFs. This must be managed carefully as safety is of utmost importance at a mine. The problem statement and objectives of the research and the outline of this document will be given in this chapter.

1.2 PROBLEM STATEMENT AND OBJECTIVES

With the increasing cost of electricity and the strained platinum mining industry the need arises for this mining industry to reduce their electricity costs. MVFs are one of the major consumers of electrical energy at a deep level platinum mine and therefore the focus of this study will be to reduce the electricity costs of the fans.

The objective of this study is to investigate the effect of controlling main ventilation fan inlet guide vanes for a deep level platinum mine to reduce the electrical costs. Controlling the IGVs will not only reduce the electrical costs but will also have an effect on the efficiency and quantity of air delivered by the fans. This will be simulated to determine the possible results where after a real life example will be implemented to obtain actual results to compare with the simulation. A financial analysis will be carried out to determine if it is feasible to implement this intervention.

1.3 OVERVIEW OF THIS DOCUMENT

This section gives a brief description of each chapter of the dissertation.

Chapter 1 gives a brief background and the need for the study. The problem statement and objectives of the research are given.

Chapter 2 discusses the current national electricity state in South Africa and the electricity consumption of the different end users which leads to why reduction on the electrical costs of main ventilation fans at a deep level platinum mine is important. The ventilation system of a deep level mine is described and different control methods are given emphasizing on inlet guide vanes.

Chapter 3 provides an overview of the different electricity users of the case study mine under investigation. The ventilation fans and the IGVs installed on the fans are assessed and an opportunity is identified to reduce the electricity costs on the fans. In order to prove the cost saving, a baseline for the MVFs was developed.

Chapter 4 discusses the improved IGVs that were implemented at the mine with the control philosophy. Possible savings are simulated and discussed.

Chapter 5 discusses the measurements that were taken and the results of the case study to demonstrate the successful implementation of energy efficiency strategies on MFVs of a deep level platinum mine.

Chapter 6 provides a financial analysis of the EE strategy, and discusses capital and operational expenditure and the cost saving that can be achieved.

Chapter 7 provides a summary and conclusion of the dissertation, and recommendations for future work are also discussed.

CHAPTER 2 – LITERATURE STUDY

This chapter provides a thorough literature study where focus will be given to the following. Electricity supply versus the demand in South Africa, DSM and energy efficiency in South Africa, Electrical energy usage in South African Mining, Ventilation system of a deep level mine which will discuss the primary and secondary ventilation and environmental conditions of a deep level mine, and main components of main ventilation fans and control methods for them.

2.1 INTRODUCTION

Due to the continuous increase of the electricity costs in South Africa the need arises to investigate and research new ways to reduce the electricity costs of end users. This is specifically required in the deep level platinum mining industry as they are very large consumers of electricity and their profitability has reduced significantly due to the continuous rise of operating costs, the low price of platinum and past industrial actions that took place.

Demand side management (DSM) and EE can play an essential part in the reduction of the annual electricity cost within the mining operation [1]. Numerous large electricity consumers exist on deep level mines which include; compressed air, pumping, refrigeration, mining loads, winders and ventilation [2]. Where the ventilation loads specifically the MVFs are the focus of the study.

Controlling the IGVs on the fans will have an effect on the electricity cost, quantity of air delivered and the efficiency of the fan. Utmost care should be taken when implementing an EE or DSM measure on the fans. Therefore an in-depth understanding of the main ventilation system and mine ventilation practises are required to ensure a safe and healthy environment for the mine worker [3].

This chapter addresses the electricity supply and the demand in the South African electricity sector, as well as the possibilities of DSM and EE opportunities within the mining environment. This study will also give a brief description of MVFs and IGVs of a deep level mine. Control methods on the MVFs are also discussed.

2.2 ELECTRICITY SUPPLY VERSUS DEMAND IN SOUTH AFRICA

Electrical energy in South Africa is mainly generated by Eskom, which consists of 23 power stations and has an installed total nominal capacity of 42 090 MW [4]. Compared to most of the African countries this is quite substantial. This installed capacity amounts to approximately 95% of the electricity used in South Africa [5]. Figure 1 illustrates a load profile of the electricity demand in South Africa for a typical winter and summer day. The demand in the winter months (June, July and August) is mainly higher because of consumers making use of heating equipment. This is especially observant in the evening peak times which are between 17:00 and 19:00 in the winter months, where a difference of between 4 MW and 5 MW exists. This is an increase of approximately 15% of the maximum demand which is quite substantial.

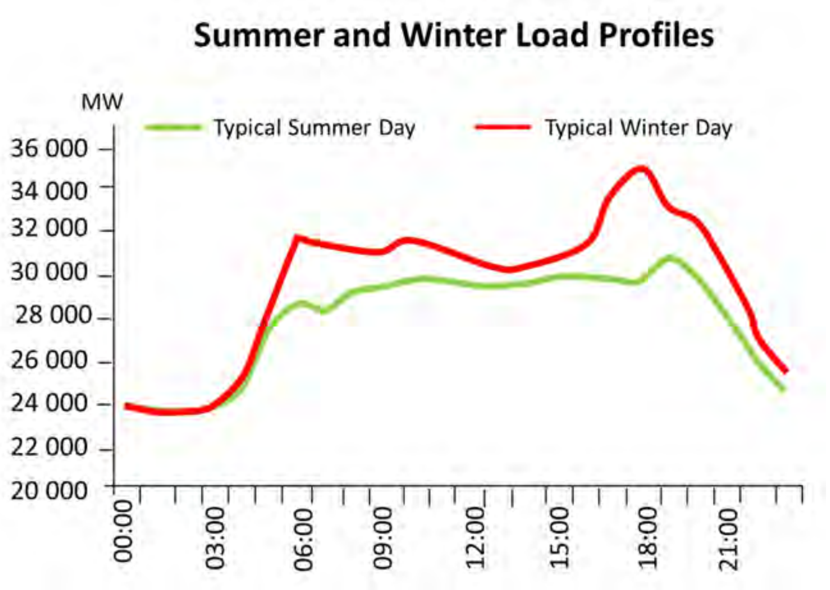

Figure 1: Summer and winter load profiles [4].

The total available capacity is about 41 990 MW. Table 1 and Figure 2 illustrate the distribution between the different sources utilised by Eskom [4]. From these statistics it's illustrious that more than 85% is generated from coal because South Africa has a large coal reserve, and can therefore be sold at a reasonable price [6]. The other 15% is generated from pump storage, Hydro, gas fired and nuclear sources [7]. However, coal-burning contributes significantly to climate change, hence reducing electricity consumption in South Africa is necessary if we want to move towards a low-carbon economy.

Table 1: Total generation capacity [4].

Type	Capacity [MW]
Coal	35 721
Nuclear	1 860
Gas Fired	2 409
Hydro	600
Pump storage	1 400

Apart from Eskom, independent power producers also added a combined total of 1.8 GW of capacity to the electricity grid by means of wind and photovoltaic sources [8]. The cost of the generating electricity between coal, wind and photovoltaic sources are given below:

- Average price of generating electricity from coal = 33 c/kWh during the day and 22 c/kWh during the night [8].
- Average price of generating electricity from wind or photovoltaic sources = 216 c/kWh [8].

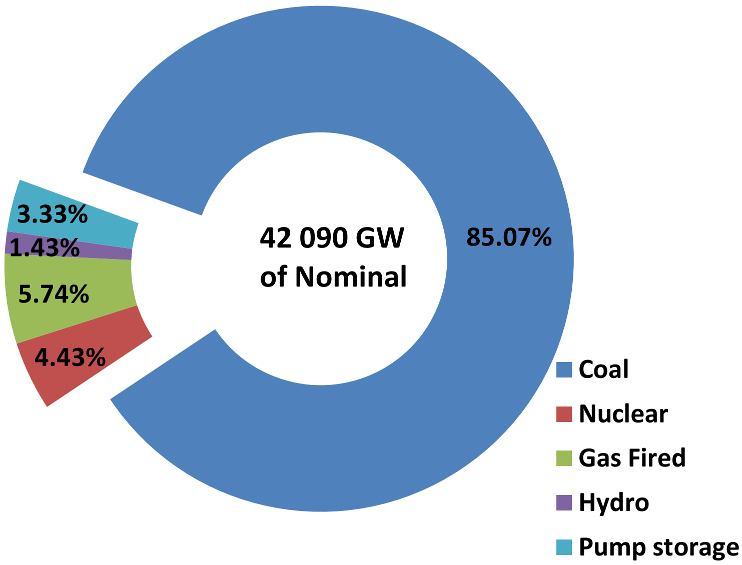

Figure 2: Breakdown of nominal capacity by fuel source [4].

Due to the significant escalating cost in generating electricity, the high operational expenses of Eskom, and the low price of electricity in the past compared to the rest of the world, the price of electricity has gone up significantly compared to previous years. Figure 3 shows the average c/kWh on the Mega Flex (MF) tariff price increase for the year 2009 to 2016.

An example of the significance on the tariff increases indicated in Figure 3 below is as follow. If a 1 kW electrical machine was running 24 hours a day for a full year in 2009 the average electricity cost to operate this machine would have cost about R 3 066. If the same electrical machine is operating 24 hours a day for a full year in 2016 the total electrical operating cost will be about R 8 146. The electrical operating cost from 2009 to 2016 equates to about 2.7 times more which is fairly significant. This is a total increase of 166% over a 7-year period. This is mainly due to two high increases in 2010 and 2011.

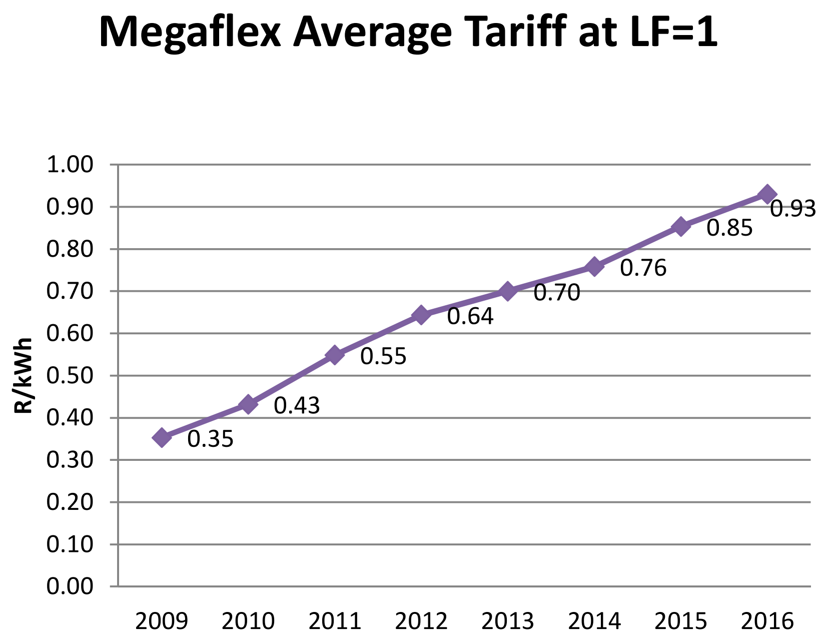

Figure 3: Eskom tariff increase [9] [10] [11] [12] [13] [14] [15].

Eskom has many consumers which they supply with electricity, and during the 2014/2015 financial year they have sold 216 274 GWh of electricity [4]. By using the average MF tariff given in Figure 4 the total sales for this period was about R 164 billion. The total sales are divided into the different consumers as presented in Table 2 with each consumer's total GWh purchases for the financial year 2014/2015 [4]:

Table 2: Different electricity consumers in South Africa [4].

Total usage [GWh]	**216 274.00**
Municipalities	91 051.35
Industrial	22 489.68
Mining	3 103.58
International	173.80
Residential	9.39
Commercial	0.42
Agriculture	0.011
Rail	0.00015

Figure 4 shows the percentage distribution between the different consumers. The three major consumers are the municipalities, industrial and mining clients which account for about 80.6% of the total sales. The rest of the smaller consumers (international, residential, commercial, agriculture and rail) accounts for about 19.4% of the total sales.

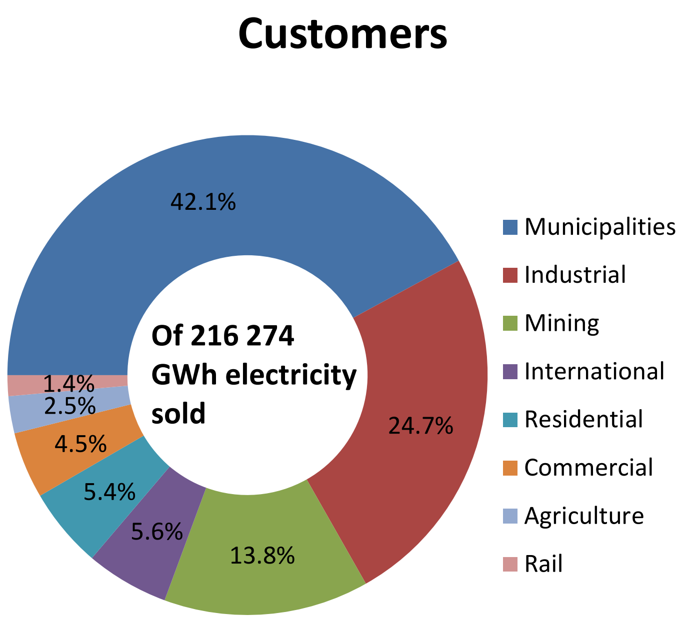

Figure 4: Eskom electricity sales [4].

Due to the substantial growth demand, ageing of the old power stations and the shortage of supply, Eskom is planning to add 11 126 MW of electricity to the electrical grid by 2019 [16]. This is about 26% of the total capacity that is currently available. The capacity that is planned to be added is presented in Table 3. This is divided into coal, pumped storage and renewable generation.

Table 3: Planned capacity expansion from Eskom [16].

Project	Planned						Total
	Year to 31 March 2014	Year to 31 March 2015	Year to 31 March 2016	Year to 31 March 2017	Year to 31 March 2018	Year to 31 March 2019	
Grootvlei (return to service)	30						**30**
Komati (return to service)	100						**100**
Medupi (coal fired)		1 588	1 588	1 588			**4 764**
Kusile (coal fired)		800	800	800	1 600	800	**4 800**
Ingula (pumped storage)		1 332					**1 332**
Sere wind farm (renewable)		100					**100**
Total (MW)	130	3 820	2 388	2 388	1 600	800	11 126

In the first half of 2015 Eskom shed 82 days of load resulting in 709 hours and 1 095 GWh of unserved energy respectively. Load shedding was being implemented due to a constrained grid and to avoid a national black out which can occur when the electricity usage becomes more than what can be supplied by the grid. Together with this, the total amount of energy that was unserved is illustrated in Table 4. From Table 4 and Figure 1 it can be observed that due to the higher demand in the winter, specifically during evening peak times, the electricity grid becomes more constrained [8]. This indicates that South Africa is energy as well as a demand constrained. Therefore there is a need to reduce energy as well as the demand in order to address these issues.

The findings illustrate that there is a requirement for DSM and EE, specifically in the winter months during evening peak times. These interventions will assist Eskom in lowering the required demand which can be achieved in shorter times than implementing of new generating capacity. This will be addressed in the following section of this document.

Table 4: Hours of load shedding in the first half of 2015 [8].

Hour of the day	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Total Sheds
0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	5	1	1	7
7	0	0	0	5	4	1	10
8	0	12	0	7	9	4	32
9	0	12	2	7	9	4	34
10	3	15	2	12	10	5	47
11	5	15	2	12	10	5	49
12	5	17	4	12	11	5	54
13	5	17	4	12	11	5	54
14	5	18	4	12	12	5	56
15	5	18	4	12	12	6	57
16	5	22	6	16	20	16	85
17	5	23	6	23	34	27	118
18	5	25	6	26	34	29	125
19	5	24	6	26	34	30	125
20	5	23	6	24	32	30	120
21	5	23	5	24	30	30	117
22	0	5	0	0	0	0	5
23	0	0	0	0	0	0	0
Total	58	269	57	235	273	203	1095

2.3 DSM AND ENERGY EFFICIENCY IN SOUTH AFRICA

DSM can be described as implementing predictable changes to a customer's load and demand profile. DSM aims to reduce peak loads immediately over short periods of time [17] [18]. This is essential as a short term solution due to the constraint grid and the long implementation time of new generating capacity [19] [20] [21]. This is also a much cheaper solution to implement as seen from Figure 5 [22].

From Figure 5 it can be observed that the cost (R/MW) of adding new generating capacity to the grid is almost double the cost of the most expensive DSM option and about four times the cost of the cheapest DSM option. On the industrial and mining customers of Eskom many DSM options exist which ranges from efficient lighting replacements which are the most expensive but has a low impact on the demand to EE options on fans and pumps, which has the lowest cost but a bigger impact on the demand reduction.

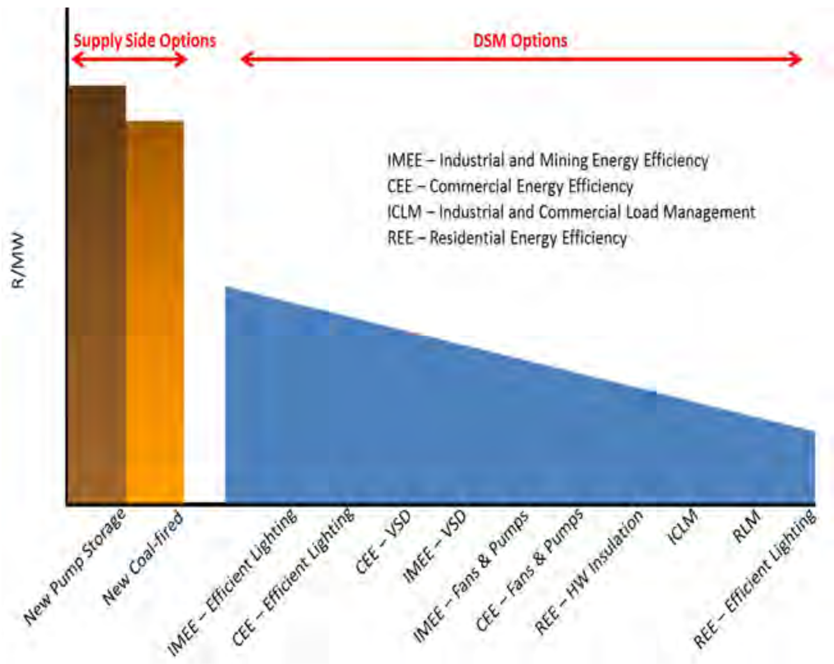

Figure 5: Supply side options versus DSM options [22].

The two most common methods that exist in the industry are LM and EE [23]. The LM approach is to reduce peak demand and electricity during peak hours to off-peak hours. An example of a load profile of a typical LM intervention is presented in Figure 6 [24]. It can be observed from this figure that the load during the peak hours have been shifted to the off-peak hours. This is typically achieved by optimising and changing a process to accommodate for this shift in load.

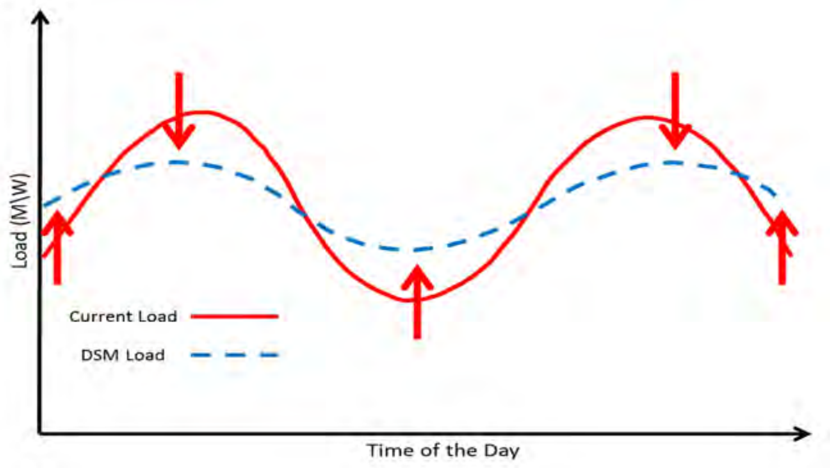

Figure 6: DSM LM approach [22].

LM consists of mainly three methods; Load shifting, Peak clipping and Valley filling [25] [26] [27]. Load shifting is where the load is shifted from peak times of the day to off-peak times of the day. Load shifting does not reduce the average power consumption [19]. This method is mainly implemented on pumps and refrigeration plants where the process can be changed and optimised to accommodate for the shift in the electrical load to save costs by using the energy in inexpensive periods.

Peak clipping comprises of the reduction of the load during peak times by means of direct load control [19]. This method is mainly implemented on electrical loads like compressed air, where they can reduce the pressure in the evening when blasting takes place. There is a definite energy saving in this method but could lead to production loss if not managed properly.

Valley filling includes increasing the load in off-peak times [19]. This method is not found much in the industry and does not reduce the average power consumption. This however saves cost as more electrical energy is used in off-peak times and less in peak times.

The EE approach aims to reduce overall consumption by replacing old inefficient equipment with more efficient equipment, or by optimising an entire process or processes. An example of a load profile of a typical EE intervention is presented in Figure 7 [24]. It can be observed that the averaged power consumption decreased which will result in cost savings.

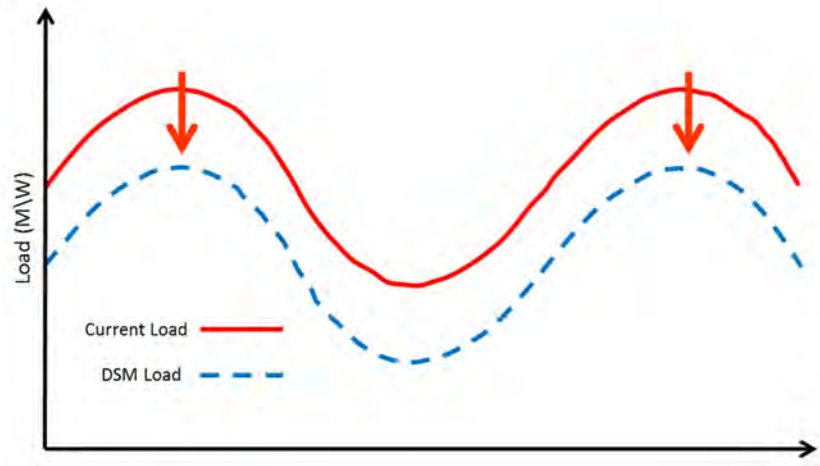

Figure 7: DSM EE approach [22].

Eskom has its own DSM division called Integrated Demand Management (IDM). Their core focus is to promote EE, DSM, energy management programmes, energy conservation schemes, and demand response programmes. This is all to assist in reducing the demand of end users to avoid possible national supply failures. This is all achieved through different funding and support to the different customers [28]. Figure 8 shows historic performance of projects implemented through IDM funding [29]. An increase is observed from 2007 to 2010 because of the national energy crisis that existed in that time and immediate action was required to assist in the constrained grid. Eskom currently has 1 356 MW of capacity available for control during evening peak times [4].

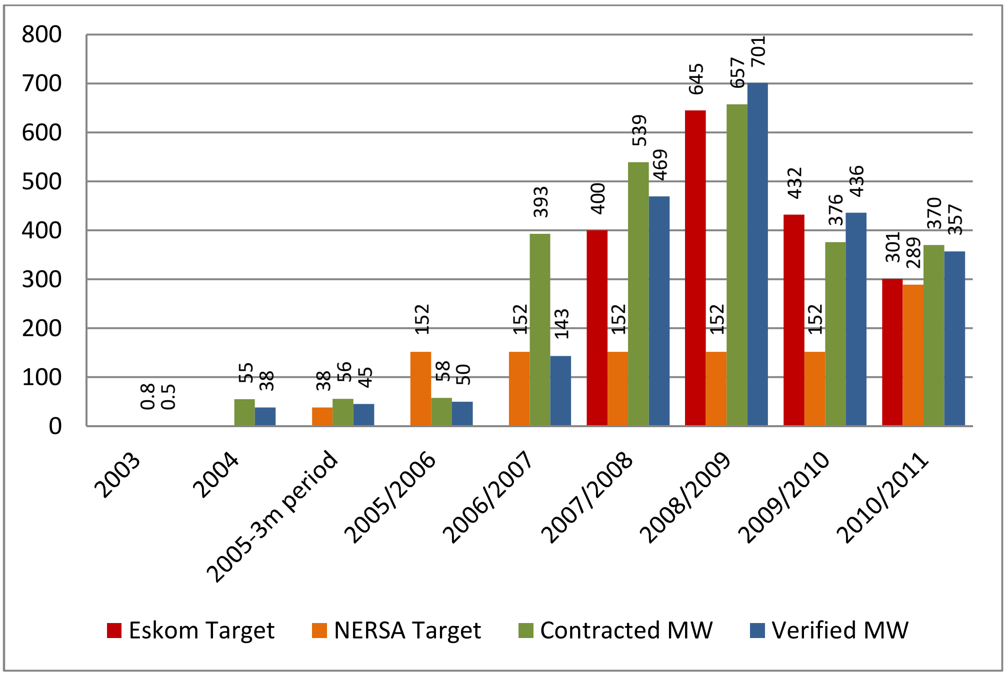

Figure 8: Target and verified MWs [29].

From October 2013 to January 2015 no funding was available from Eskom IDM and therefore the savings were below target. The reason for this was because the demand was below the supply due to added capacity to the national grid. In February 2015 it was announced that funding will be available again, but only for projects being completed during the next three years [4]. Table 5 shows the required targets after these project implementations. Only energy savings and energy efficiency targets could be met.

Table 5: Eskom Verified DSM and internal energy efficiency savings [4].

Measure and unit	Target 2019/20	Target 2015/16	Target 2014/15	Actual 2014/15	Actual 2013/14	Actual 2012/13	Target met
Demand savings (evening peak), MW	304	187	246	172	410	595	No
Energy savings GWh	1 862	763	592	816	1 363	2 244	Yes
Internal energy efficiency, GWh	n/a	1	10	10	19	29	Yes

Eskom IDM has three core sectors namely mining & industrial, commercial and agriculture [28] [29]. Due to the fact that the mining and industrial sector consists of about 50% that can be seen from Figure 9 and because the focus of the study is deep level mining, the next section will describe the electricity usage in the mining industry [28] [29].

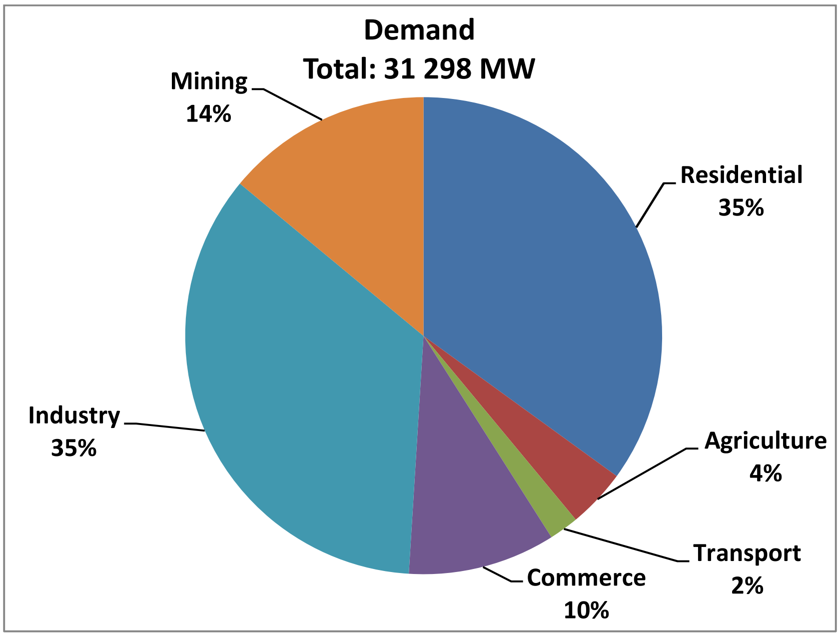

Figure 9: Electricity consumption per sector [29].

2.4 ELECTRICAL ENERGY USAGE IN SOUTH AFRICA MINING

The South African mining industry consumes about 13.8% of South Africa's electricity supply. In 2015 this amounted to 29 846 GWh of electricity [4]. The gold mining industry consumes about 47%, the platinum mining industry about 33% [30] and the other mining industries about 20%. Within the mining environment the following users exist [6]:

- Mining
- Compressed air
- Ventilation
- Pumping
- Winders
- Refrigeration
- Others

The other users are consisting of surface and underground lighting, office buildings and residential users of the mine. A breakdown of their usage is presented in Figure 10.

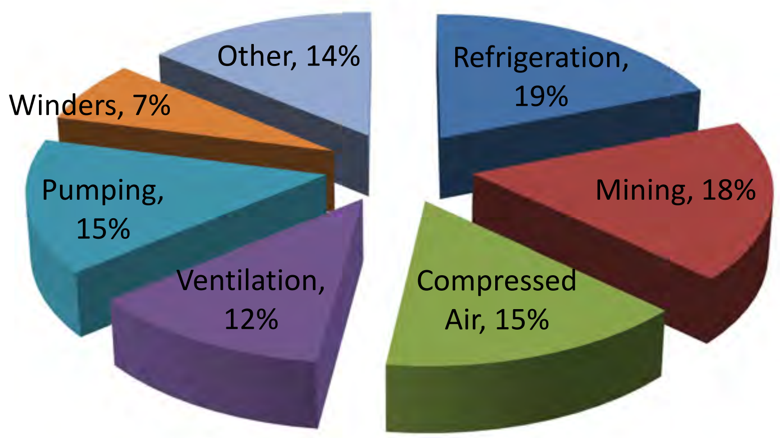

Figure 10: Average mine process electricity consumption [31].

From Figure 10 it can be observed that the biggest consumers are refrigeration, mining, compressed air, pumping and ventilation. Many studies were done to achieve energy reduction on these loads and many DSM and EE interventions were implemented on refrigeration, compressed air, and pumping. Not many studies have been done on reducing the electricity cost on the ventilation systems of a mine. Improvement on reducing the electricity cost is therefore possible on the ventilation loads of a deep level mine, due to the low number of DSM and EE interventions that were implemented on these loads in the past [32]. The ventilation system of a deep level mine will be discussed in the next section of the document.

2.5 VENTILATION SYSTEM OF A DEEP LEVEL MINE

2.5.1 Primary and secondary ventilation of a deep level mine

The ventilation system of a deep level mine consists of surface fans and underground fans which are supplying the mine with the necessary amount of fresh air [33]. This is to dilute noxious gasses as well as to cool down the underground working areas in order to create a safe underground working environment. This is also known as the primary and secondary ventilation systems of a mine. The demand of a ventilation system can be as high as 15MW, with the surface fans being the largest energy consumer of this system. The motor sizes of these fans range from 100kW [34] to 4MW and up to six of these fans can be required per mine [24] [33]. Figure 11 shows an example of typical main ventilation fan stations.

Figure 11: Typical mine ventilation fans [35].

The primary ventilation of a mine consists of the primary ventilation fans which are installed on the surface and in some cases are installed underground. These fans are typically found in the field and are strategically placed to ensure that all the underground working areas are ventilated. The secondary ventilation system of a mine consists of underground booster fans and auxiliary fans in the underground working areas. Figure 12 shows a typical layout of a mine ventilation system.

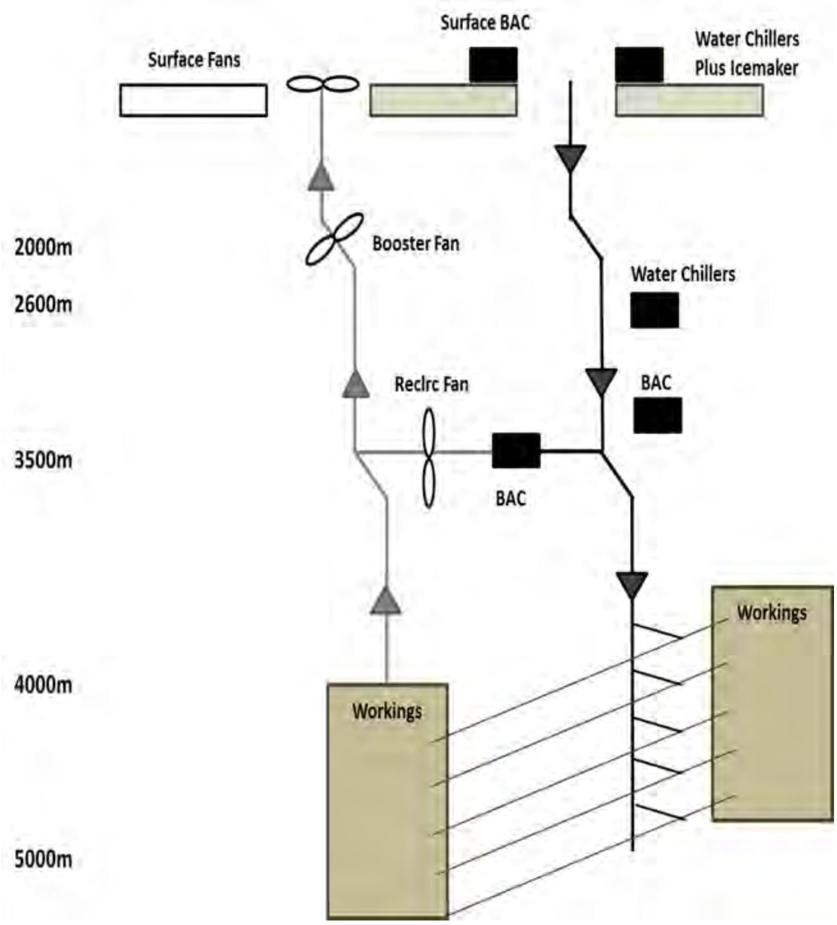

Figure 12: Typical mine ventilation layout [33].

Main ventilation fans supply the mine and the underground workings with the required amount of fresh air. This is supported by the placement of booster fans and auxiliary ventilation fans in strategic places underground [36]. This can also be observed in Figure 12 where the fans are being placed strategically underground to force air into the working areas as well as to avoid recirculation of the air. This is important because when the air is being recirculated a heat build-up will start and thus make it unsafe for the workers to enter these areas. Figure 13 shows a functional diagram of the primary ventilation system of a mine.

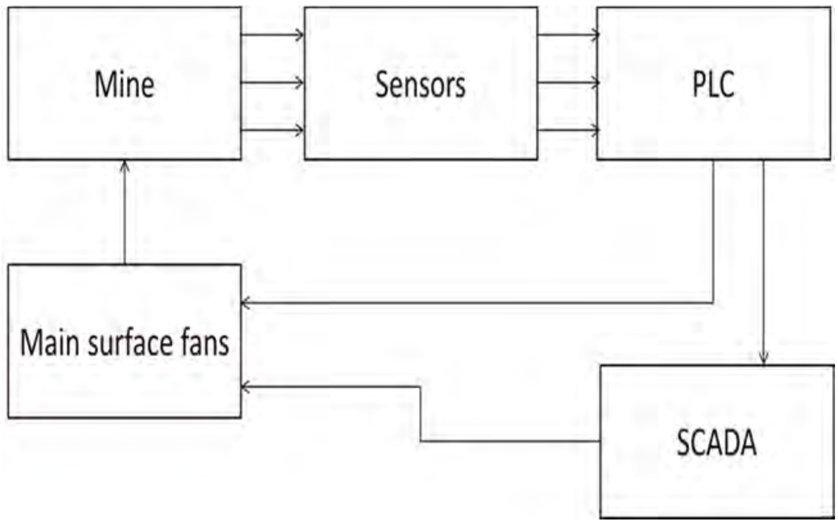

Figure 13: Functional diagram of a mine primary ventilation system

Safety is of paramount importance at a mine and therefore the mine needs to be ventilated to the legislated environmental standard. This is in place to avoid an unsafe underground working environment for the mine workers. A brief look into the environmental standards of a mine is discussed in the next section.

2.5.2 Environmental conditions

There are two controllable parameters when it comes to environmental control of an underground mining operation. This is the quantity of air delivered and the temperature of the air. The main fans supply the total air that is required for the underground working areas as well as for cooling down the mine. Refrigeration plants and bulk air coolers are required where excessive heat is generated [33]. For safe working conditions the WB temperature and DB temperature should not exceed 27.5°C and 37°C [37] respectively [36] [38] [39].

The role of refrigeration in a deep hard rock mine is to keep the working environment below the above mentioned temperatures [40]. Because this process is so expensive, it is used only as a last resort in the development of the mine, when normal ventilation is not sufficient [33].

The role of ventilation is to supply the underground mining employees with enough fresh air and to dilute and remove dust, gasses and heat from the mine [33] [41]. A typical hard rock mining cycle is presented in Figure 14 with the different shifts described in Table 6. This will be critical as it has an influence on the amount of air that is required during certain times of the day.

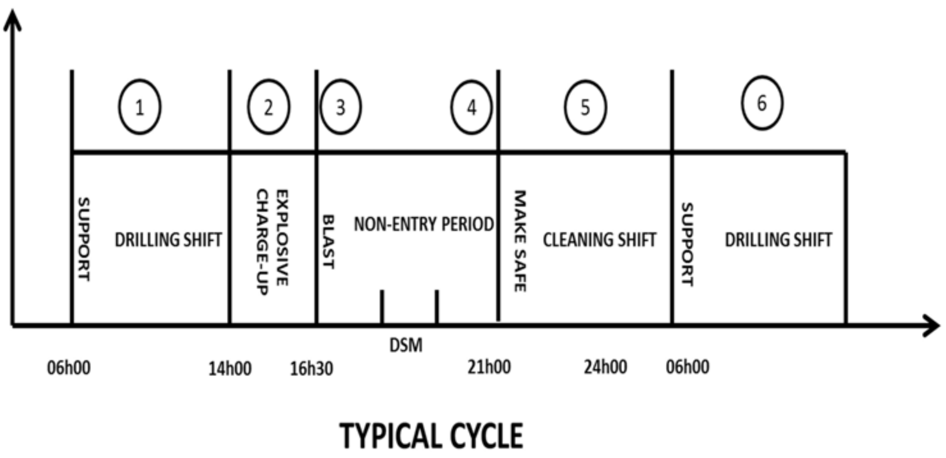

Figure 14: Typical mining cycle fo a deep hard rock mine in South Africa [42].

In many cases it is not necessary for refrigeration where the ventilation air generates enough cooling power for the working areas [43]. It is not easy to specify a required overall air quantity. Air quantities in South African deep level mines range from 3kg/s to 6kg/s per 1000 ton of rock mined per month [41]. There is also no relationship between the mean stope phase velocity and the amount of air delivered. The required mean stope phase velocity on mines is about 1m/s [41].

Table 6: Description of a typical mining cycle [42].

Correspond to number in Figure 14	Description
1	Drilling shift starts at about 06h00, with many men underground drilling blast holes – vent/cooling system must be at 100% to cool men.
2	When drilling is complete, blast holes are charged-up with explosives and detonation system is setup – mine is then evacuated.
3	At about 16h30, explosives are detonated and the workings are filled with large amounts of smoke, gas and dust – mine remains evacuated.
4	After some time, the smoke gas and dust is exhausted by the ventilation but the mine remains evacuated until gas levels are acceptable.
5	Cleaning shift then clears the broken rock – this involves many men underground – vent/cooling system must be at 100% to cool men.
6	Once rock is cleared, and after support work, drilling shift begins again

Due to the fact that many mines were designed during times of cheap electricity, they have a ventilation system that is over designed, and therefore a lot of air and electrical energy is wasted [43]. As these fans are running continuously this wastage is costing the mine a significant amount of money. The following section discusses the main surface fans of a mine and some energy savings and management techniques that can be used to address the issue.

2.6 MAIN SURFACE FANS OF A DEEP LEVEL MINE

A fan is a machine which takes continuous air from a lower pressure converting it into a higher pressure which is necessary to overcome the resistance of a mine [44]. In the mining environment a MVF is used to supply the underground working areas with the required fresh air. Three types of fans are commonly available [45].

- Centrifugal flow fans.
- Axial flow fans.
- Mixed flow fans.

Of these three fans centrifugal flow and axial flow fans are most commonly used for ventilation systems. Important facts with regards to these fans are mentioned below.

Axial flow fans are typically used in low pressure high volume applications (typically < 2 kPa). They are preferably used underground on the following applications: Booster fans, auxiliary fans, bulk air cooler fans and in line duct fans. Common surface fan applications include: main fan stations (especially coal mines), bulk air cooler fans and cooling towers [35].

Centrifugal fans are typically used in high pressure applications (typically 2 – 8 kPa). They are commonly used as main surface fans in deep level mines [35]. Since the focus of the study is on deep level mines, focus will henceforth be given to centrifugal fans.

2.6.1 Control Methods for Centrifugal fans

Basically, three methods exist for controlling the output of a centrifugal fan. This is [42] [45] [46]:

- System damper control.
- Speed control via VSD
- IGV control.

Each of these control methods are described briefly below.

System damper control

A damper acts as a throttling device which decreases the volume delivered and increases the system pressure. These are easy and inexpensive to install but provides a low reduction in power with a high reduction in flow. For instance reducing the airflow to 40% the result in power reduction will be 12%. Figure 15 shows a typical fan curve which includes the pressure/volume, power and resistance curves [42] [45] [46]. From this the volume reduction by means of damper control reduces the volume from Q_1 to Q_2 and the power from P_1 to P_2. This is due to the system pressure that increased and therefore the system curve moved up from point D to E on the curve.

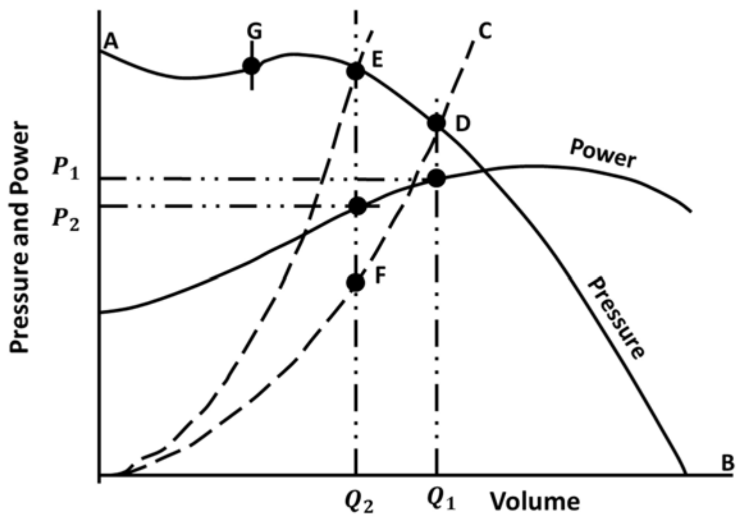

Figure 15: System damper control on a centifugal fan [45].

Speed Control

Speed control by means of a VSD is the most efficient method of flow control [47]. VSD's allow for speed adjustments over a continuous range of airflows. Figure 16 shows a typical fan curve which includes the pressure/volume and power and resistance curves for a fan system where VSD's are installed. From this it can be observed that over a full volume range, power savings are achievable. To speed down the fan by means of a VSD does not have an effect on the system curve of the fan. Due to high investment cost it is not economically feasible to retrofit existing systems, but VSD's should indeed be considered in the process of new fan installations [42] [45] [46].

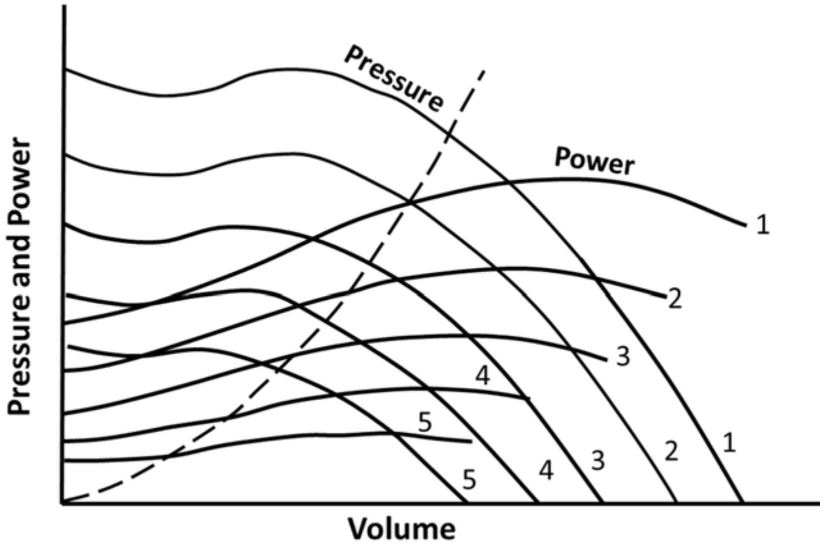

Figure 16: Speed Control on a centrifugal fan [45].

IGV Control

Inlet guide vanes are installed in the airstream in front of the fan impeller which produces a pre-swirl before entering the impeller if the vanes are partially closed. The effect of the pre swirl can be observed in Figure 20. This reduces the work of the impeller, and therefore the pressure and the volume delivered by the fan is also reduced. This has the effect that different pressure/volume and power curves for each setting of the IGV are produced. Figure 17 shows a typical fan curve which includes the pressure/volume and power and resistance curves for a fan system where IGV's are installed. Here it can be observed that there is a significant power saving by reducing the airflow into the impeller with IGVs. IGVs are very cost effective for airflows between 80% and 100%. For airflows below 80% the efficiency reduces [42] [45] [46].

From the above it can be seen that the IGV control and the VSD control are more efficient and provides better power savings than system damper control. IGV control will be investigated in this study due to the lower capital investment required. The next section of the document will provide details on the components of a main fan and IGV for understanding purposes to the rest of the document.

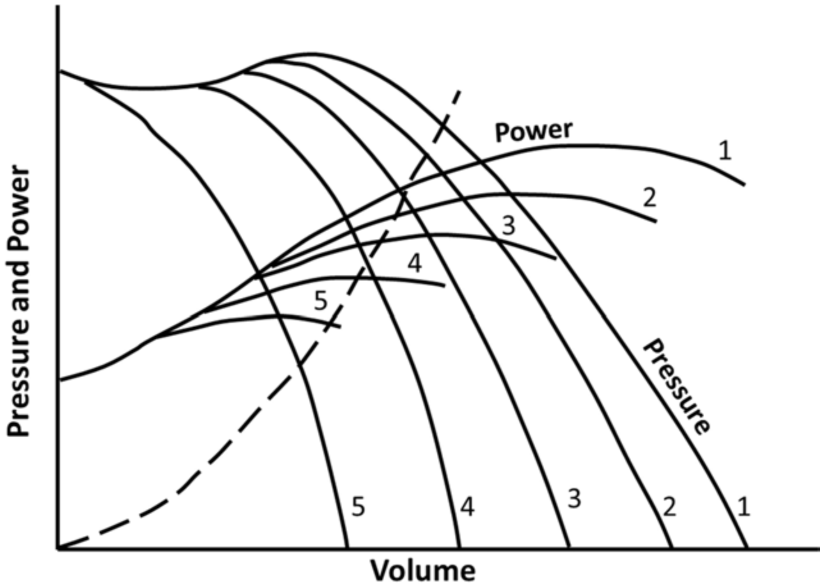

Figure 17: Inlet Guide Vane Control on a centrifugal fan [45].

2.6.2 Main components of a main surface fan and IGV

Figure 18 shows a simplified drawing of the main components of a centrifugal fan that is used for extracting fresh air through a deep level mine [48]. Component A in the drawing is the motor house of the fan. The following components are typically installed in the motor house of the fan:

- Fan motor for rotation of the fan impeller.
- Motor switchgear.
- Control and instrumentation circuitry.
- Fan shaft that is connected to the impeller and the brake system.

Component B is the evase of the fan. The impeller directs the contaminated air through the evase. Component C is the fan casing where the impeller of the fan is installed. The impeller is rotating in a clockwise direction, directing the air through the evase. Component D is the inlet cone of the fan where the inlet guide vanes are installed to pre-swirl the moving air through the impeller. Component E is the fan drift which is connected to the surface and allows the air to flow smoothly towards the fan.

These are the typical main components of a main ventilation fan which is important to the rest of the document. Focus will be given to the IGVs that are installed within the inlet cone of the fan.

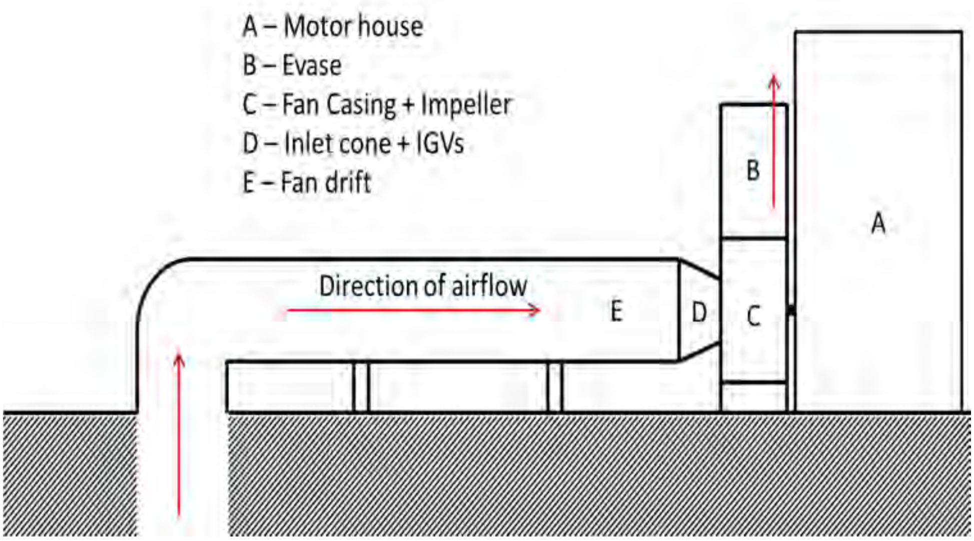

Figure 18: Main components of a main surface fan.

IGVs are commonly installed at the inlet of centrifugal fans for start-up purposes of the fans. This procedure is typically as follows:

- When the fan is switched of and isolated, the IGVs are being fully closed by hand with a gearbox that is connected to the IGV operating lever.
- When the fan needs to be started again, it is started up with the IGVs in the closed position. After about 30 seconds the IGVs are then being opened by the gearbox again to the fully open position.

The reason for this is to keep the start-up current as low as possible to avoid paying for going over their peak demand as per the MF tariff.

A typical IGV installed on a main ventilation fan system is presented in Figure 19. The main components of an IGV are illustrated in Figure 43 and consist of the following main components (The numbers in brackets below corresponds to the numbers in Figure 43):

- Hub of the IGV (2).
- Vanes of the IGV (6).
- Bushes of the IGV (8).
- Hub stays of the IGV (9).
- Control arm of the IGV (12).

A list of the full set of components of an IGV is presented in Figure 43 in Appendix A of the document. The hub of the IGV consists of all the main moving parts which allows for rotation of the vanes of the IGV. A list of the full set of components of the hub is presented in Figure 44 in Appendix A of the document.

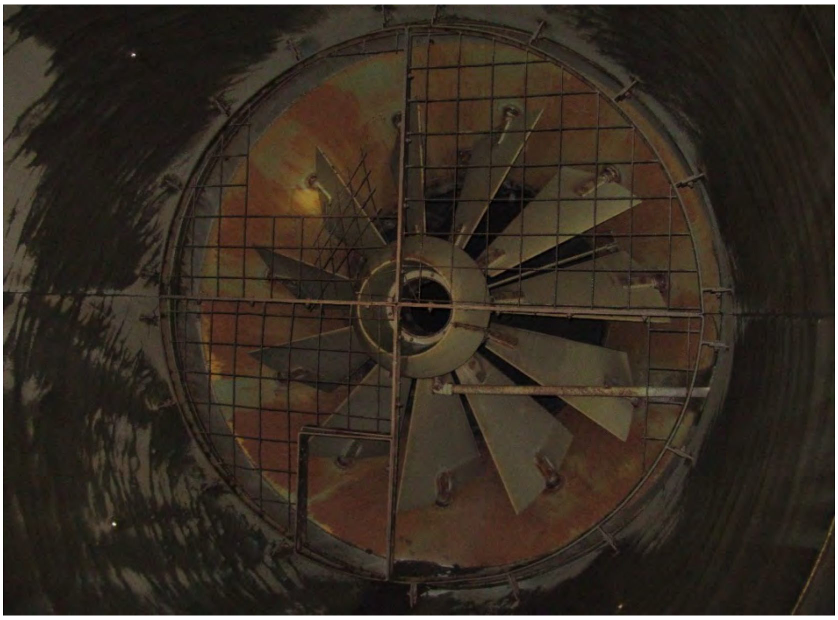

Figure 19: Typical IGV fitted on main surface fan.

The IGVs control the airflow into the impeller by means of a pre-swirl. The load on the impeller will reduce if the swirl is in the same direction of the rotating impeller. This will in turn reduce the load on the motor. It is visually presented in Figure 20 by a CFD study showing the swirl of the air towards the impeller [49]. At the different angles there are different volume/pressure/power operating points that was noted in a previous section of the document. By reducing the angle of the IGVs could result in potential power savings and therefore cost savings if it can be done by still supplying the underground working areas with the required amount of fresh air.

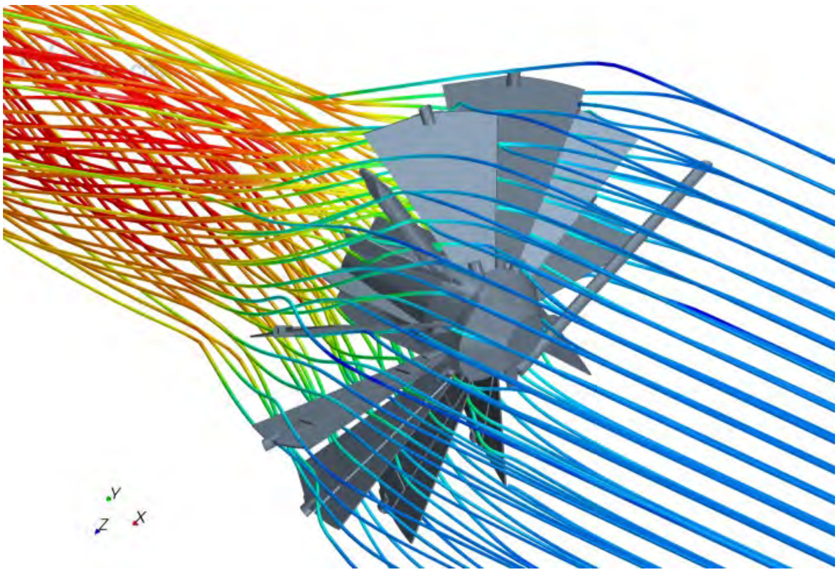

Figure 20: Pre swirl of air moving through IGV [49].

2.7 CONCLUSION

This chapter indicates the importance of EE and DSM in South Africa, specifically within the deep level mining industry. Due to the large impact that the deep level mining business has in the South African electricity market, as well as the rising cost of electricity, it is obvious that this sector needs to investigate more possible solutions for energy savings.

The potential exists for more EE and DSM initiatives to be implemented on the ventilation system of a deep level mine. IGV control on MVFs was identified as a possible solution. In the next chapter a deep level mine's electricity consumers and MFVs are investigated which will be used as a case study for the research. A baseline will also be developed for these fans in order to determine the possible impact of the savings.

CHAPTER 3 – CASE STUDY MINE A

This chapter provides an overview of the different electricity users of the case study mine under investigation. The ventilation fans and the IGVs installed on the fans are assessed and an opportunity is identified to reduce the electricity costs on the fans. In order to prove the cost saving, a baseline for the MVFs was developed.

3.1 INTRODUCTION

MVFs at a deep level platinum mine are big consumers of electrical energy. From previous research this was determined to be about 12% of the total usage of a deep level mine. These fans are the primary supply of fresh air for the underground workers and it dilutes pollutants from the underground working areas. A specific deep level platinum mine outside of Rustenburg was selected as a case study to investigate a possible EE and DSM opportunity on the MVFs of the mine in order to reduce the electrical cost of the mine.

This chapter addresses the mine being studied with regards to total electricity consumption and ventilation operational requirements. By implementing cost effective and reliable EE and DSM interventions, significant savings in electrical energy are achievable. A baseline will also be developed from available data received from the mine in order to measure the performance after implementing the EE measure.

3.2 DESCRIPTION OF MINE A

Mine A is located outside Rustenburg on the Western limb of the bushveld which consists of two shafts. Mining operations have stopped at the second shaft and it has been placed under care and maintenance. When placed under care and maintenance, only the necessities are required and therefore most electrical equipment are switched off. The first shaft is investigated in this study due to minimal opportunities that will exist at the shaft that is under care and maintenance. Mining occurs between 300m and a 1000m below surface and both the Merensky and UG2 reef are being mined at this shaft. The life span of mining operations for this mine is until 2038 [50] [51]. Due to 20 plus years of life span of the mine, it should be feasible to investigate possible electrical cost savings opportunities at this mine.

Figure 21 shows a photo from outside mine A. The distribution of the energy usage to the different electricity consumers of mine A is addressed in the next section of the document.

Figure 21: Mine A shaft [50].

3.3 DISTRIBUTION OF DIFFERENT ELECTRICITY LOADS

The main 6.6 kV substation of mine A had electrical kWh meters installed on all the incomers and feeders to the different consumers of the mine. The meters installed are ION, PM 820 power meters from Schneider Electric and logs all power, current, voltage and energy data. All of this data is logged in a database for historic purposes. Historic data for a full year was retrieved from the database in order to determine the total usage as well as the distribution of the different consumers. Figure 22 shows one of the reticulation diagrams of the main substation.

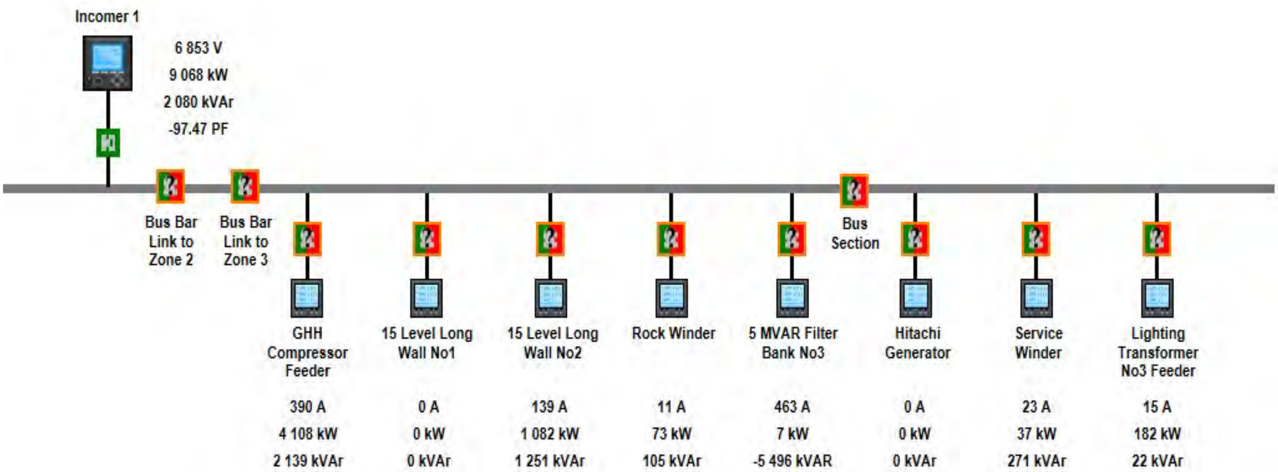

Figure 22: Electrical reticulation diagram of mine A.

The mine has an operational capacity of about 13MW and is mainly divided into the following big consumers:

- Compressed air
- Mining loads
- Underground fans
- Surface fans
- Change Houses
- Refrigeration
- Pumping
- Winders

A breakdown of the percentage of electricity consumption of the different processes at mine A is presented in Figure 23. The four biggest users are compressed air, mining loads (includes underground auxiliary fans), winders and the ventilation load. It can be observed that the ventilation load of the mine is about 10% of the total consumption as it was expected from the literature that was reviewed in chapter 2 of this document. DSM interventions were already implemented on the compressed air system of the mine. Due to the focus of the study the next section is directed on the main ventilation fans of mine A.

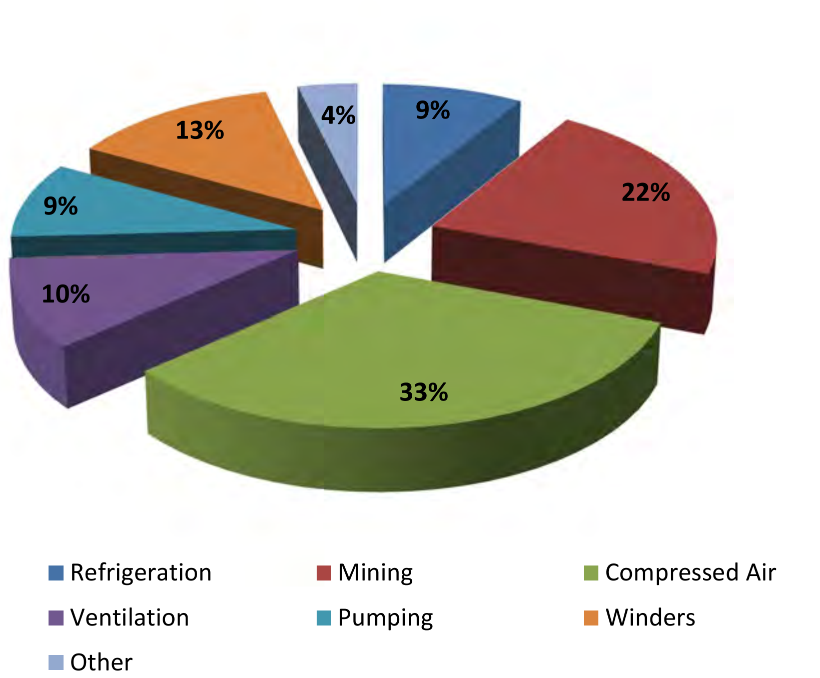

Figure 23: Average process electricity consumption of mine A.

3.4 VENTILATION FANS OF MINE A

The MVFs of mine A were visited and a thorough inspection was conducted with the necessary testing done to be able to do a feasibility study to determine a baseline and possible electrical power savings. At this time there were only two main surface fans installed with the third fan still in the planning phase of the mine. The two fans are both in operation and continuously operating, where the third fan will be used as a backup fan. A backup diesel generated fan is also available in case of emergencies and can only deliver half of the volume of air of one of the main fans. In case of an emergency (i.e one or both of the fans fail) the diesel fan will be brought into operation which will supply sufficient air underground while the underground workers evacuates. Figure 24 shows an image of the outside of the MVFs at mine A.

Figure 24: Main ventilation fans of mine A.

Each fan has a design criteria as presented in Table 7 in order to deliver maximum flow and pressure for the specific mine. These are important guidelines when possible power savings are determined. During the design phase of the mine the fans were designed for the purpose of when the mine is at its peak production point, therefore delivering maximum volume at the required pressure. This is not necessarily where the fan is operating and with the necessary testing the operating point was determined and is discussed in the next section.

Table 7: Mine A surface fan characteristics

Description (per fan)	Value
Motor Capacity (kW)	750
Volume flow (m^3/s)	120
Pressure (kPa)	4.5
Impeller speed (rpm)	740
Impeller Diameter (m)	2.69

The total installed power capacity is therefore 1500kW which can deliver a total volume flow of $240m^3/s$ at a pressure of 4.5kPa for the two fans that are installed and in operation. During the feasibility study the fans were physically measured with a Pitot tube and manometer. The same procedure was followed as described in chapter 5 to determine the volume flow. The fans were measured operating at the following points:

- Power of 1307 kW.
- Total volume flow of $313m^3/s$ (This is the flow when both fans are in operation).
- Pressure of 2.85 kPa

The fans operating at this point can be described to the fact that the mine is still expanding and that there are many leakages (old mining areas that are not sealed down and still absorbing the fresh air) which require more volume that is produced at a lower pressure. In essence, this causes the fan to run at a low efficiency and can be observed from the fan curves in appendix B. Mine A currently also requires 233 m^3/s of fresh air and therefore it is being over ventilated. From this information it can be seen that there is an opportunity to reduce the amount of air delivered underground and still ventilate the mine to the required standard which can lead to potential electrical power savings.

The fans were also operating with the IGVs in the fully open position to allow for maximum airflow. No control could have been implemented due to the IGVs that were in a poor condition. This is described in the next section of the document.

3.5 IGV'S INSTALLED ON MINE A VENTILATION FANS

During the feasibility study it was noted that the IGVs that were installed during the first construction of the main ventilation fans had some mechanical failures. These failures occurred due to the lack of maintenance and high air moisture levels that caused corrosion on the central hub of the IGV's. The excessive movement of the IGV's eventually led to the failure of the corroded parts in the central hub. Fan impellers and casings were severely damaged by loose IGV blades as illustrated in Figure 25. A new method had to be introduced to rectify the safety concerns of the IGV design that led to the failures.

Figure 25: Typical IGV failure.

A typical example of these failed parts can be seen in Figure 26 and Figure 27. It can be observed that failures occurred on the control arms on the operating ring of the hub and on the bushes connecting the blades to the hub. When this happens and the IGVs are moving the blades fall out at a certain point and is then sucked in by the impeller causing severe damage to the fan impeller and casing.

Figure 26: Failure in IGV Hub

Figure 27: Damaged bushes of IGV

During the feasibility study of the system a baseline was also determined. This was done in order to determine possible savings of the system to determine if it is feasible to implement an IGV system to save on electrical cost. This will also be used after implementation of the system to determine the actual electrical cost savings that were achieved.

3.6 BASELINE OF MAIN FANS

The historic power, and fan test data were used for baseline determination. From the measurements taken during the feasibility study, the following baseline was determined for the volume and the pressure from the fan tests:

- Operating volume: 313m^3/s (This is the flow when both fans are in operation).
- Operating pressure: 2.85 kPa

A full month of half hourly recorded power data was used to determine the electrical baseline for the study. This was an acceptable data set to use because the fans are continuously in operation with the IGVs in the fully open position. The baseline was divided into a weekday, Saturday and a Sunday. This is divided into different days as the mining cycle is different for these days, as well as different rates that are being used by each type of day for the MF tariff that is applicable to the mine. The baseline was determined by averaging the power values for each half hourly time stamp of a day for all the days of the month. If the fan was off for any reason on that specific day it was excluded from the calculation. The baseline is illustrated in Figure 28.

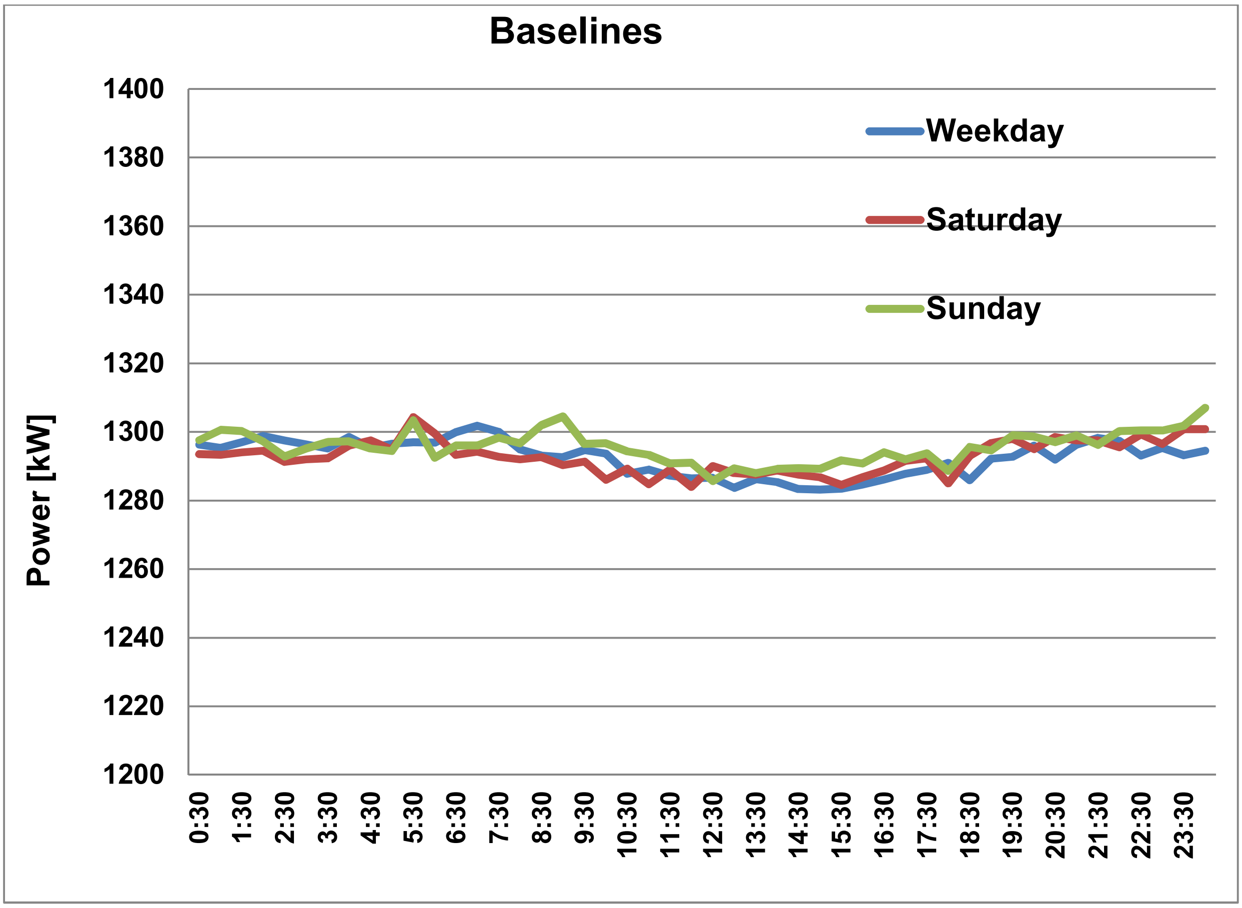

Figure 28: Weekday, Saturday and Sunday electrical baseline.

Table 8 provides the half hourly values over a 24-hour period which is divided between weekdays, Saturdays and Sundays. There is not a significant difference between the three types of days but it is important when the cost savings are calculated later in the document and when the Eskom MF tariff is taken into account.

Table 8: Half hourly electrical baseline values

Time	Weekday [kW]	Saturday [kW]	Sunday [kW]
00:30	1296	1294	1298
01:00	1295	1293	1301
01:30	1297	1294	1300
02:00	1299	1295	1297
02:30	1298	1291	1293
03:00	1296	1292	1295
03:30	1295	1292	1297
04:00	1298	1296	1297
04:30	1295	1298	1295
05:00	1297	1295	1294
05:30	1297	1304	1303
06:00	1297	1300	1293
06:30	1300	1293	1296
07:00	1302	1294	1296
07:30	1300	1293	1298
08:00	1295	1292	1297
08:30	1293	1293	1302
09:00	1293	1290	1305
09:30	1295	1291	1297
10:00	1294	1286	1297
10:30	1288	1289	1294
11:00	1289	1285	1293
11:30	1287	1289	1291
12:00	1286	1284	1291
12:30	1287	1290	1286
13:00	1284	1288	1289
13:30	1286	1288	1288
14:00	1285	1289	1289
14:30	1283	1288	1289
15:00	1283	1287	1289
15:30	1283	1285	1292
16:00	1285	1287	1291
16:30	1286	1289	1294
17:00	1288	1292	1292
17:30	1289	1292	1294
18:00	1291	1285	1289
18:30	1286	1293	1296
19:00	1292	1297	1295
19:30	1293	1298	1299
20:00	1296	1295	1299
20:30	1292	1299	1297
21:00	1296	1298	1299
21:30	1298	1298	1296
22:00	1297	1296	1300
22:30	1293	1299	1300
23:00	1295	1297	1300
23:30	1293	1301	1302
00:00	1295	1301	1307

3.7 CONCLUSION

It was identified that an electrical energy savings opportunity exists on the main ventilation fans of mine A. This is noted from the actual measurements that were taken which show that the mine is being over ventilated. This saving can be achieved by supplying the mine with the required volume of $233m^3/s$. This reduction can be achieved by means of IGVs which will reduce the power consumption significantly.

In order to further investigate the effect of reducing the volume flow, changes in the IGV system were required to facilitate an actual reduction in flow. Changes were implemented and a discussion on this will be reserved for the next chapter. The control philosophy as well as the savings will be given in the next chapter of the document.

CHAPTER 4 – DESIGN AND IMPLEMENTATION OF THE SYSTEM

Chapter 4 discusses the new improved IGV system that was implemented at the case study mine and the implementation strategy that was followed. The control philosophy that was followed is also described and this chapter concludes with a baseline that was determined for the main ventilations fans.

4.1 INTRODUCTION

Unfortunately, the IGVs installed on mine A were in a very poor condition. Because of this poor condition there were failures on the IGVs which caused damage to the fan. It was therefore necessary to replace them and this was done before a new control system was implemented and tested.

This chapter addresses the new IGVs that were implemented as well as the control philosophy that was followed. Possible savings are also simulated and discussed. This is important as the control of the IGVs has an effect on the underground working environment and therefore all measures need to be in place before the IGVs can be controlled.

4.2 NEW IMPROVED INLET GUIDE VANE SYSTEM AND IMPLEMENTATION STRATEGY

The initial design flaws as described in chapter 3 were addressed by introducing new and improved IGV sets where the parts that failed are enclosed in the central hub as illustrated in Figure 29. This enclosed hub is filled with grease for smooth operation and out of contact of the corrosive air and can be seen in Figure 30. Appendix A shows the detailed drawings of the new IGVs that were installed.

These IGVs have the following key improvements:

- IGV blades, support stays and actuating arms are hot dip galvanized.
- The central hub (the outside of which is painted with high quality corrosion prevention system) provides a completely sealed enclosure for the internal moving parts.
- Internal components of the hub are machined mild steel, coated and packed with heavy duty multi-purpose grease.

In order to prevent costly asset damage and the costly downtime in the event of a major failure, it is advised that the mine enter into a regular schedule of maintenance after installation. Costs of the maintenance will be addressed in chapter 6 of this document.

Figure 29: New improved IGV's.

All of the new improved IGVs are fitted with a motorised actuator which is connected to the operating lever of the IGVs and can be observed in Figure 29, and a programmable logic controller (PLC) interface to control the angle of the IGV's. The programmable actuator with its gearbox can control the IGVs by either opening or closing the vanes via a 4 – 20 mA signal from the PLC. The PLC will be the main controller of the system where the system will be controlled from.

Figure 30: Inside of the new IGV hub.

Angle indicators were installed at the electric actuators for calibration purposes. Figure 31 shows the electrical actuator with its angle indicators. A protractor is used inside the fan drift at the IGVs to calibrate the actuator at the different angles. This is important for testing, calibration and configuration purposes. Details of the calibration are given in appendix C of this document.

Figure 31: Electric actuator with angle indicators.

As part of the IGV control system a SCADA page was also developed as illustrated in Figure 32. This SCADA page interacts directly with the PLC for the control of the system. This allows for easy changes to the system when required.

Figure 32: SCADA page of the fan system.

CHAPTER 4 – DESIGN AND IMPLEMENTATION OF THE SYSTEM

A diagram of the complete control system is illustrated in Figure 33 which consists of the following:

- IGV
- Actuator
- PLC
- SCADA system
- Power meter

The power meter is for electrical power and energy measurements and was already available. The SCADA system will communicate with the PLC control system that will control the actuator which will adjust the IGVs.

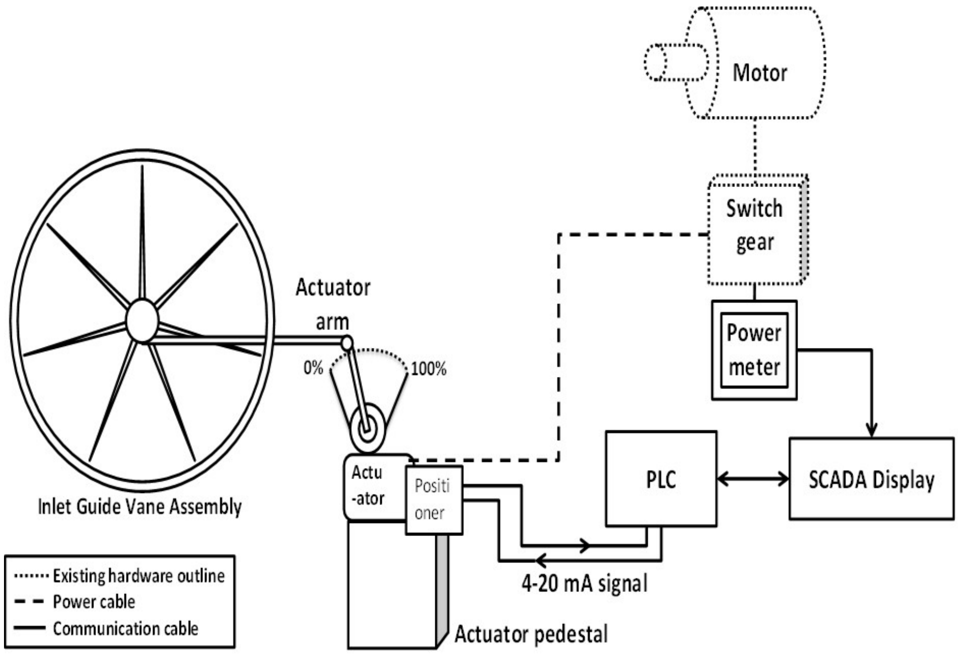

Figure 33: IGV control system components

This new installation had to happen during an off weekend of the mine. During an off weekend no mining operations take place and therefore the ventilation requirements are lower and one of the MVFs can be switched off. Based on experience, one IGV set can be installed over an off weekend. The following procedure and strategy was followed for the installation of the IGVs:

- During the feasibility study the necessary information was gathered for the design of the IGVs. Once the IGVs were manufactured, a date was arranged for the installation.
- The installation of the fan started on a Saturday morning after risk assessments, safety and toolbox talks took place.
- One of the fans was isolated and locked out by the qualified mine personnel.
- Once it was declared safe by the mine, the fan drift was opened (door available) and the existing IGV set was stripped out by qualified personnel.
- The old IGV set was removed from the fan drift and the new set carried into the fan drift.

- After the alignment was done the new IGVs were fitted and installed. Appendix B shows the installation reports for both fans.
- The actuator with the connecting rod was then connected to allow for movement of the IGVs.
- The PLC and control circuitry is then connected afterwards for fully automated capabilities.
- The IGVs with the actuator and PLC was then calibrated before system testing.

The complete mechanical installation report for both IGV sets is given in Appendix C of this document. The next section of this document describes the philosophy that was followed for the control.

4.3 CONTROL PHILOSOPHY

Before the new IGV system was implemented there was minimal control on the previous IGVs due to the failure that occurred as well as no proper research has been done in order to be able to control it within its limits. The IGVs were used only for start-up purposes as described in chapter 2. The problems to the failed IGVs have been fixed by the new IGVs that have been implemented. A philosophy to implement control on the improved IGVs will now be discussed.

By controlling the IGVs the quantity of air that the fans deliver is also controlled. If not properly controlled due to the lack of information it could have serious consequences as insufficient fresh air is being delivered to the underground working areas. By proper simulation and testing this can safely be implemented and still ventilate the mine to the required environmental standards. The control philosophy that was followed for the research is illustrated in Figure 34. This indicates all the necessary steps that need to be taken in order to control the quantity of air that will be delivered to the underground working areas.

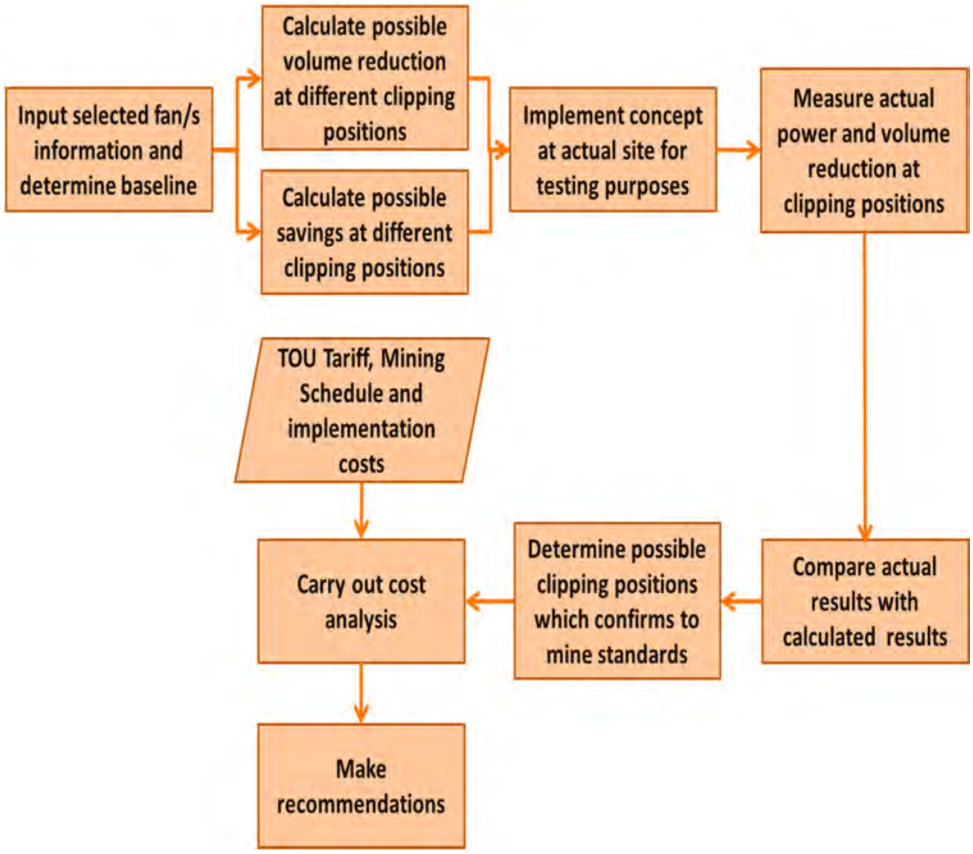

Figure 34: Control philosophy

After the necessary simulations and testing has happened the PLC can be programmed to control the IGVs to the required set points and ventilate the mine to the required environmental standards. The next section of this document gives the expected savings that were simulated.

4.4 SIMULATED SAVINGS

The possible reduction in power was determined by using the fan curves of the specific fans of mine A. The originals are illustrated in Appendix B of this document. These curves were plotted over in excel due to the information that was unavailable from the supplier because of confidentiality reasons. These curves are illustrated in Figure 35 and Figure 36 for the fan and the power curves respectively. The resistance of the mine was determined with the following equation:

$$r = \frac{P}{Q^2} \qquad (1)$$

Where,

P is the pressure of the fan in Pa

Q is the volume of air deliver by the fan in m^3/s

r is the resistance of the mine in Ns^2/m^8

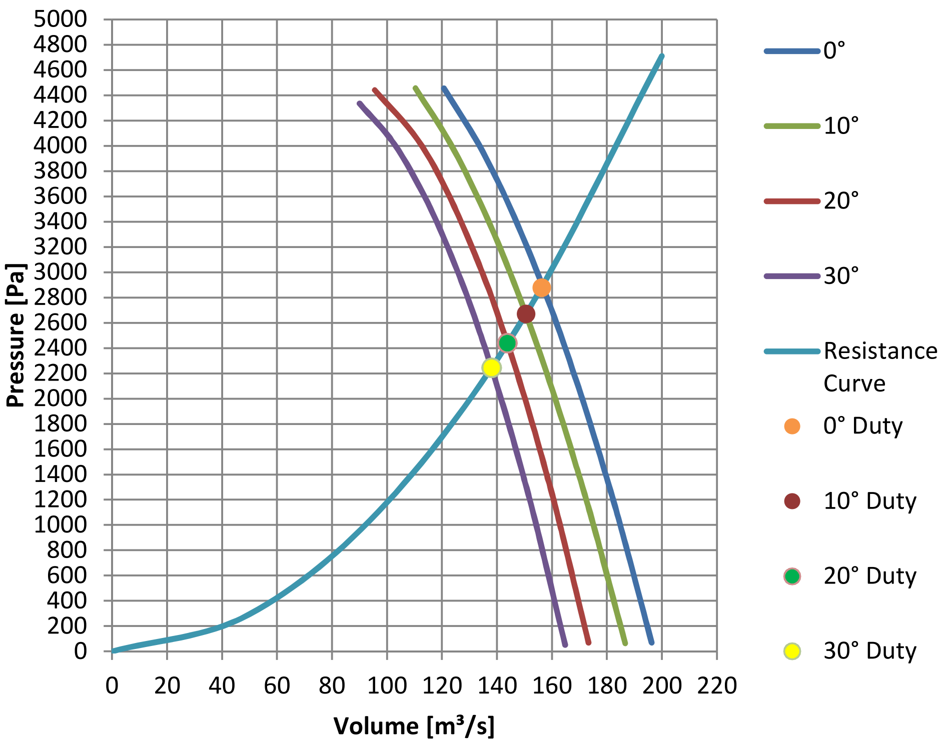

Figure 35: Mine A fan curve and resistance curve.

The duty points per fan were calculated and are illustrated in both figures. These were calculated by solving the quadratic functions for the respective intersecting points. The respective volume and pressure values are given in Table 9 for both one fan as well as when a second fan is added in parallel. This is done to accommodate for the system under investigation. In a parallel fan system the Pressure stays the same over the system but the volume of both fans are added to get the total volume delivered. Both the Pressure and volume of the system reduces.

Table 9: Simulated duty points.

	One fan		Two fans	
	Volume [m^3/s]	Pressure [Pa]	Volume [m^3/s]	Pressure [Pa]
Duty at 0°	156.31	2878.28	312.62	2878.28
Duty at 10°	150.54	2669.53	301.07	2669.53
Duty at 20°	143.84	2437.28	287.68	2437.28
Duty at 30°	138.03	2244.34	276.06	2244.34

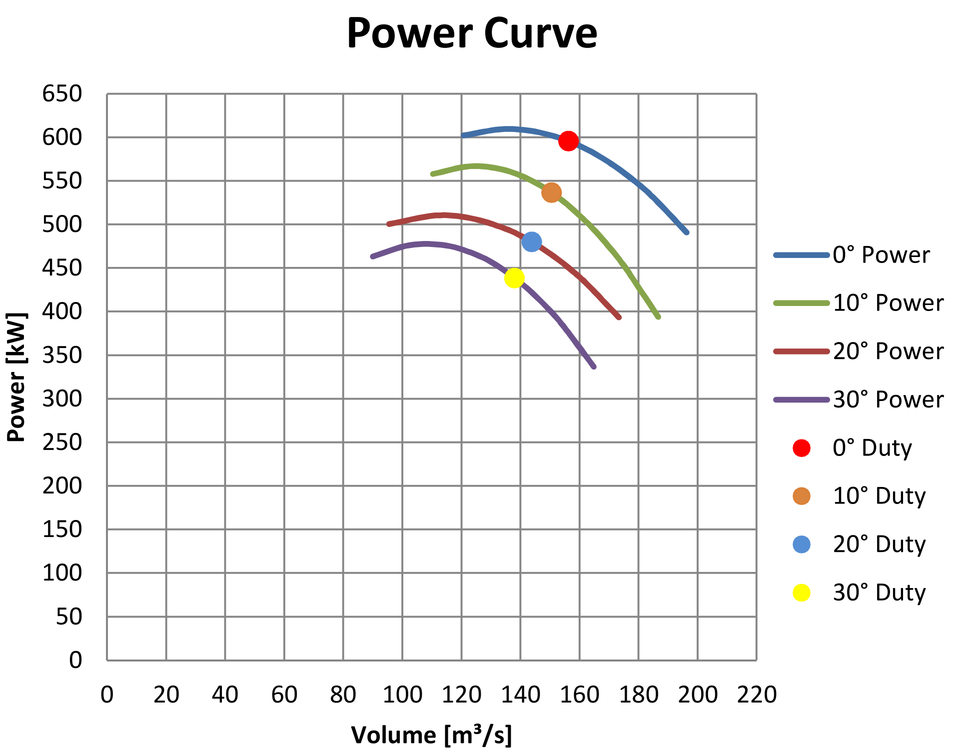

Figure 36: Power curve of the fan.

The power at the respective duty points was also calculated and the values of the volume and the power are given in Table 10. This is for both when one fan and when a second fan are added in parallel. It is observed that both the power and the volume are reduced but the reduction in power is more significant.

Table 10: Power values for simulated duty points.

	One fan		Two fans	
	Volume [m^3/s]	Power [kW]	Volume [m^3/s]	Power [kW]
Duty at 0°	156.31	595.56	312.62	1191.12
Duty at 10°	150.54	536.54	301.07	1073.08
Duty at 20°	143.84	479.91	287.68	959.83
Duty at 30°	138.03	438.67	276.06	877.33

To account for system losses the total of 20% should be subtracted from the volumes to account for these losses. This is used as a standard by ventilation officers and consultants and was discussed with them. In the actual measurements and results this 20% will be accounted for.

The information from Table 9 and Table 10 was used to determine the volume, power and pressure values for the IGV intervals from 0° to 30° for 1° intervals. The optimal IGV setting point which still supplies the mine underground working areas with sufficient fresh air were at 16°. At this IGV angle the volume of air delivered was calculated to be 234m^3/s and the respective power at this point was calculated to be 1005 kW.

Table 11: 2015/2016 Megaflex tariff [c/kWh]

Megaflex - Active energy charge	High-demand season (June – August)	Low-demand season (September – May)
Peak	274.0	97.5
Standard	103.8	72.6
Off-peak	69.8	52.5

By using the power value of 1191 kW at the 0° IGV setting an estimated power saving of 186 kW can be achieved resulting in a 16% power reduction. The respective volume reduction will be 6%. This will also deliver an annual energy saving of 1.63 GWh. By using the Megaflex tariff given in Table 11 and the time of use periods given in Figure 37 the annual cost saving is calculated to be R 1 272 769.

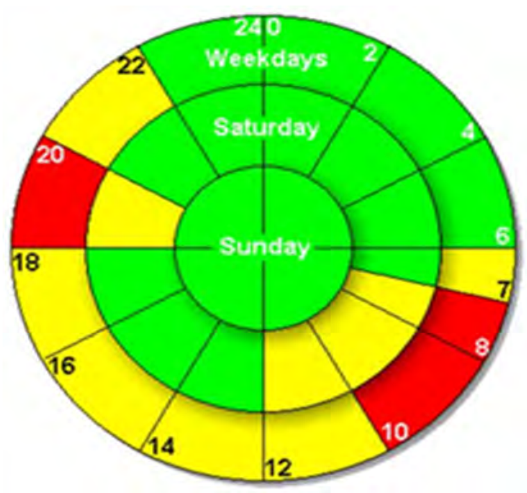

Figure 37: Eskom defined time of use periods (peak, standard, off-peak)

4.5 CONCLUSION

By implementing EE strategies on MVFs of a mine holds the potential for substantial power and energy savings. By implementing the improved IGV system demonstrates that these savings can be realised and still ventilate the mine to the required standard. A simulated power reduction of up to 16% is achievable with the resultant volume reduction determined as 6%.

The next chapter of this document gives the actual results that were achieved. This was achieved by the necessary testing on the fan system and using the measured values to determine the reductions.

CHAPTER 5 – RESULTS

This chapter provides the results of the IGV control system, and discussed the measurements that were taken to determine the results.

5.1 INTRODUCTION

Based on the simulation in the previous chapter the possibility exists to implement an EE strategy on the MVFs with IGV control and still ventilate the mine to the required standard. By measuring the fan conditions at different IGV settings, significant power reductions can be achieved.

This chapter addresses the results that were achieved by the system and how the system was assessed to deliver these results.

5.2 MAIN FAN MEASUREMENTS

After the new improved system was implemented, the necessary tests had to be done on the system in order to determine what the actual savings could be. This also gave the relevant mine personnel the necessary information to have made an informed decision of the control that was implemented on the IGVs.

The fans were tested according to the industrial fan testing in situ (ISO 5802:2001) together with a ventilation consultant. In summary the following were measured on surface at the MVFs:

- Fan static pressure.
- Fan velocity pressures at the determined positions calculated from Figure 38 at angle positions 0° and 30°. At angle positions 10° and 20° the centre row was measured.
- Fan Power, voltage, current and power factor.
- Barometric pressure on surface.
- The temperature inside the drift of the fan.

This was measured at four different IGV settings. The different angle positions that were measured were 0° (fully open), 10°, 20°, and 30°. This was to compare the actual results with the simulated results.

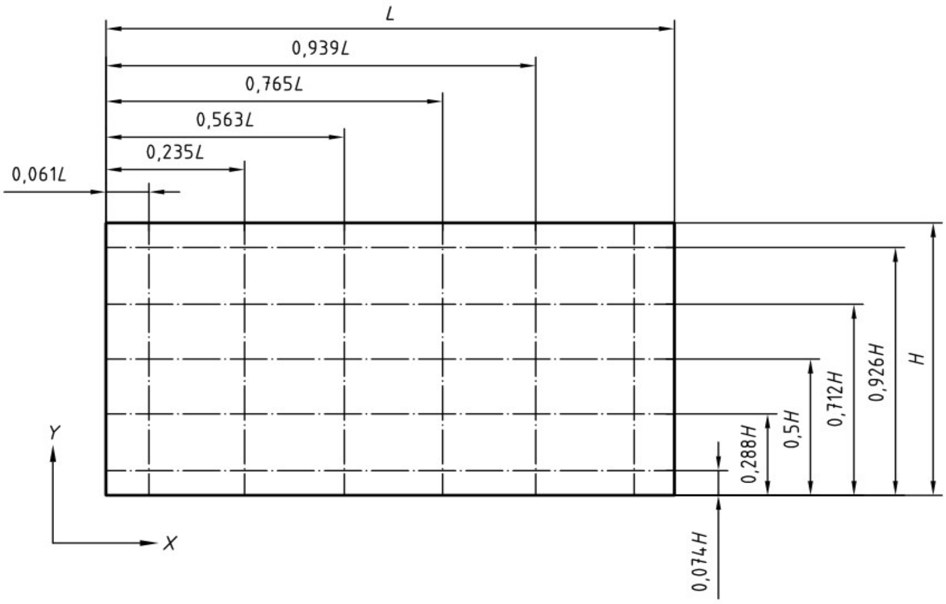

Figure 38: ISO 5802:2001 standard for positioning of fan measurements

The measurements that were taken from fan 1 at the 0° IGV position is given in Table 12 and Table 13. This is given as an example and will be used in the next section of the document to determine the volume and efficiencies of the fans at the different IGV positions. The results achieved will be given for all the IGV positions.

Table 12: Velocity pressure grid measured at fan 1 at the 0° IGV position.

Fan 1							
0° Duty - F1							
Velocity Pressure Grid							
	0.18	*0.71*	*1.31*	*1.69*	*2.30*	*2.82*	*Average*
0.22	21	58	213	199	222	190	150
0.86	37	1	105	169	232	226	128
1.50	9	38	119	173	213	161	119
2.14	338	64	168	177	224	325	216
2.78	13	72	163	171	243	308	162

Table 13: Static pressure and power measurements for fan 1 at the 0° IGV position.

Description	Value
Side gauge static [Pa]	3050.00
Power factor	0.83
Supply Voltage [V]	7026.00
Motor Current [A]	65.00
Absorbed Power [kW]	657.00
Internal drift Temp [°C]	19.8
Barometric Pressure [kPa]	89.91
Drift area [m^2]	9
Fan curve Density [kg/m^3]	0.97

5.3 SYSTEM RESULTS

The following variables were calculated to be able to determine the actual volumes and pressures of the fans:

- Air density inside the fan drift.
- Corrected static pressure inside the fan drift.
- Average velocity pressure inside the fan drift.
- Average volume flow inside the fan drift.
- Air power of the fan.
- Efficiency of the fan.

The variables were calculated with the following equations for each fan at each IGV setting:

$$\rho_d = 3.4678 \times \left(\frac{B_p - P_s}{1000 \times (273.15 + T_d)}\right) \quad (2)$$

$$P_{sc} = \frac{P_s}{\frac{\rho_d}{\rho_{fc}}} \quad (3)$$

$$P_v = \frac{1}{n} \times \sum_{i=1}^{n} x_i \quad (4)$$

$$V_p = \left(\frac{P_v \times 2}{\rho_d}\right)^2 \quad (5)$$

$$Q = V_p \times A_d \quad (6)$$

$$P_A = P_{sc} \times Q \quad (7)$$

$$\eta = \frac{P_A}{P_E} \quad (8)$$

Where,

- ρ_d is the drift air density in kg/m³.
- B_p is the barometric pressure in Pa.
- P_s is the static pressure measured at the fan in Pa.
- T_d is the temperature inside the fan drift in °C.
- P_{sc} is the corrected static pressure of the system in Pa.
- ρ_{fc} is the air density of the fan curve in kg/m³.
- P_v is the velocity pressure measured inside the fan drift in Pa.
- n is the number of velocity pressure measurements per IGV setting.
- x_i is the value of each individual velocity pressure measurement.
- V_p is the average velocity pressure inside the fan drift in m/s.
- Q is the average volume flow inside the fan drift in m^3/s.
- A_d is the area of the fan drift in m^2.
- P_A is the air power of the fan in kW.
- η is the efficiency of the fan as a percentage.

The actual power that was measured, and the actual pressures and volumes that were calculated from various actual measurements are presented in Table 14. A definite reduction in power as well as volume can be noted as the IGVs position moves from 0° to 30°. The power values presented in the tables below are instantaneous readings of the power meter when the testing of the system took place.

Table 14: Absorbed power and air volume measurements.

	Power [KW]			Pressure [kPa]			Volume [m^3/s]		
IGV Angle	**Fan 1**	**Fan 2**	**Total**	**Fan 1**	**Fan 2**	**Total**	**Fan 1**	**Fan 2**	**Total**
0° (100% Open)	657	650	1307	2.88	2.82	2.85	156	164	321
10°	616	607	1223	2.71	2.72	2.71	149	157	306
20°	567	571	1138	2.48	2.56	2.52	141	151	293
30°	527	540	1067	2.30	2.33	2.32	135	147	282

From the above the reduction in volume and power is calculated and is presented in Table 15. From here, the percentage reductions were calculated and are presented in Table 17.

Table 15: Power reduction and volume of air reduction.

	Volume Reduction [m³/s]			Power Reduction [kW]		
IGV Angle	**Fan 1**	**Fan 2**	**Total**	**Fan 1**	**Fan 2**	**Total**
0° (100% Open)	0.0	0.0	0.0	0	0	0
10°	7.6	6.8	14.4	41	50	91
20°	15.1	12.9	28.0	90	86	176
30°	21.2	17.6	38.8	130	117	247

At the 30° IGV setting the respective volume and power reductions from the simulation were 12% and 26% respectively, compared to the 12% and the 19% from the actual results. This is illustrated in Table 16 below.

Table 16: Comparison between simulated and actual results.

	% Volume Reduction		% Power Reduction	
IGV Angle	Simulated	Actual	Simulated	Actual
0° (100% Open)	0%	0%	0%	0%
10°	4%	5%	10%	7%
20°	8%	9%	19%	13%
30°	12%	12%	26%	19%

This is 7% less power that can be reduced on the system at this specific IGV setting. This can be described to that the actual system that is not an ideal case with many external factors that can influence it.

Table 17: Percentage power and volume reduction.

	% Volume Reduction			% Power Reduction		
IGV Angle	**Fan 1**	**Fan 2**	**Total**	**Fan 1**	**Fan 2**	**Total**
0° (100% Open)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10°	4.9%	4.3%	4.6%	6.2%	7.6%	6.9%
20°	9.7%	8.3%	9.0%	13.7%	13.1%	13.4%
30°	13.6%	11.2%	12.4%	19.8%	17.8%	18.8%

The effects of the clipping on the IGVs on the efficiencies of the fans are presented in Table 18. From this a significant drop in efficiency is noted when the IGVs are moved from the 0° to the 30° position. A 9% reduction is observed which is because of the lower power reduction against the volume reduction that was determined.

Table 18: Effect of clipping on the efficiency of the fan.

	Power[KW]			Air Power			Fan Efficiency		
IGV Angle	**Fan 1**	**Fan 2**	**Total**	**Fan 1**	**Fan 2**	**Total**	**Fan 1**	**Fan 2**	**Total**
0° (100% Open)	657	650	1307	450	463	456	68%	71%	70%
10°	616	607	1223	402	428	415	65%	71%	68%
20°	567	571	1138	350	387	368	62%	68%	65%
30°	527	540	1067	310	342	326	59%	63%	61%

The actual duty points that were determined from the actual measurements are plotted on the fan curve and illustrated in Figure 39. This indicates that the simulation compared to the actuals was fairly accurate as the measured duty points for both of the fans correspond to the simulated ones given in chapter 4 of this document.

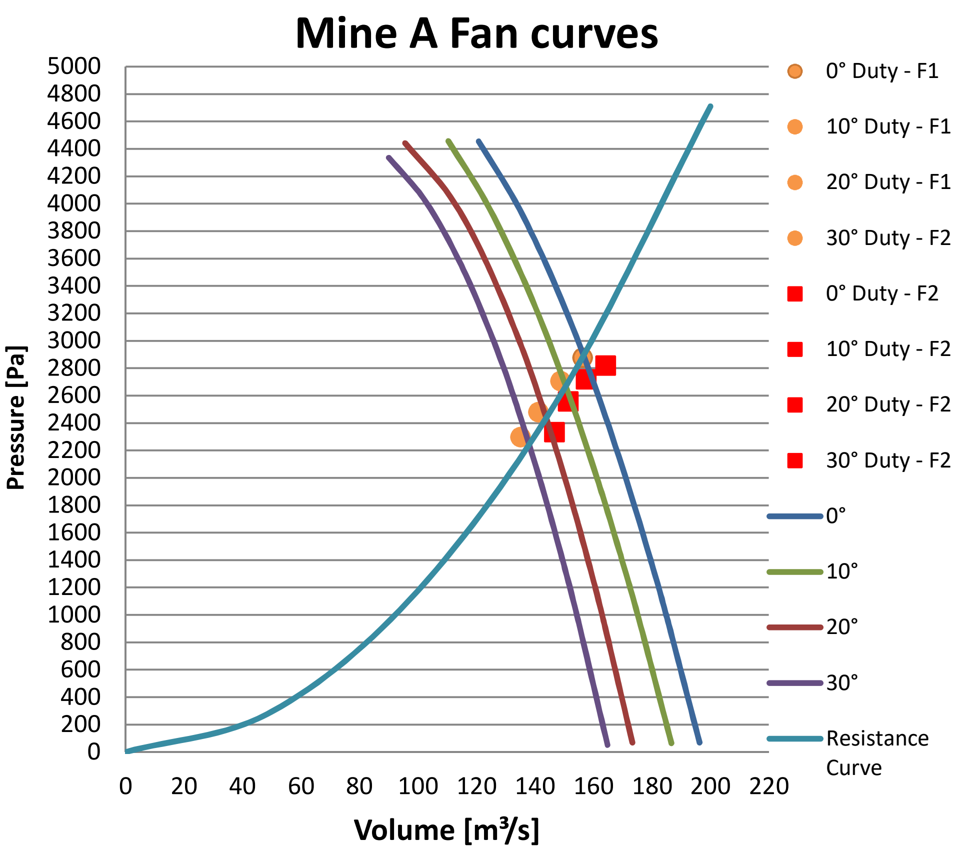

Figure 39: Mine A fan curve, including clipped duty points.

From the above measured results the clipping point of the IGVs were determined to be at 20°. This was based on the 20% losses on the 293m^3/s of air delivered at this duty, therefore an actual volume 234.4m^3/s delivered after the losses are accounted for.

With the IGVs positioned at a 20° angle a significant reduction in power was achieved as can be observed in Figure 40, Figure 41 and Figure 42. The baseline determined in chapter 3 has been plotted against the actual savings that were achieved for three months for Weekdays, Saturdays and Sundays.

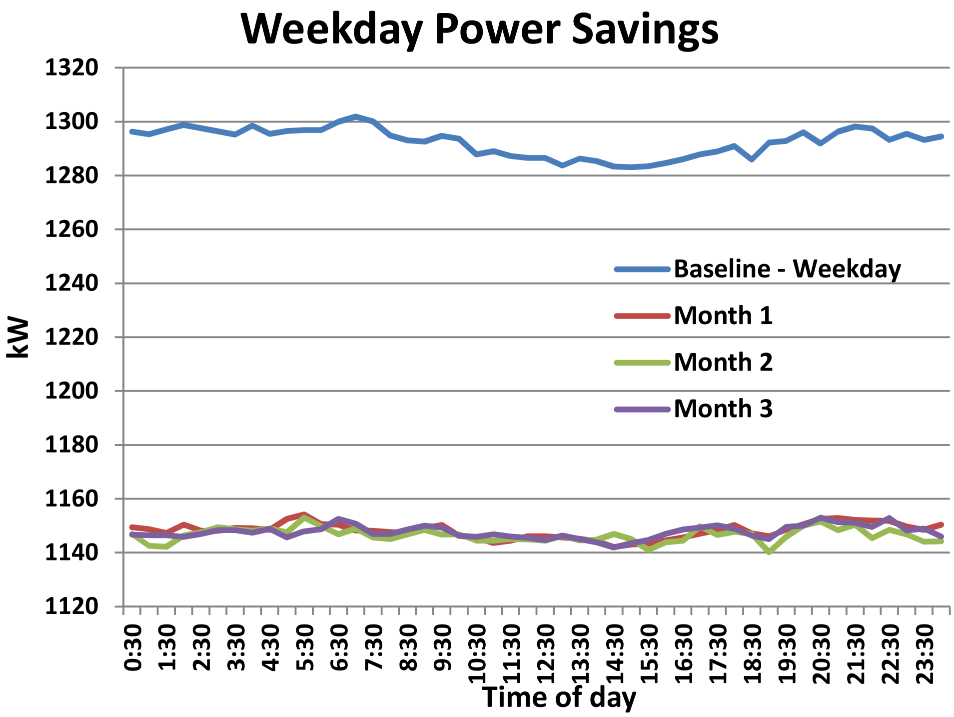

Figure 40 Weekday power savings of three months

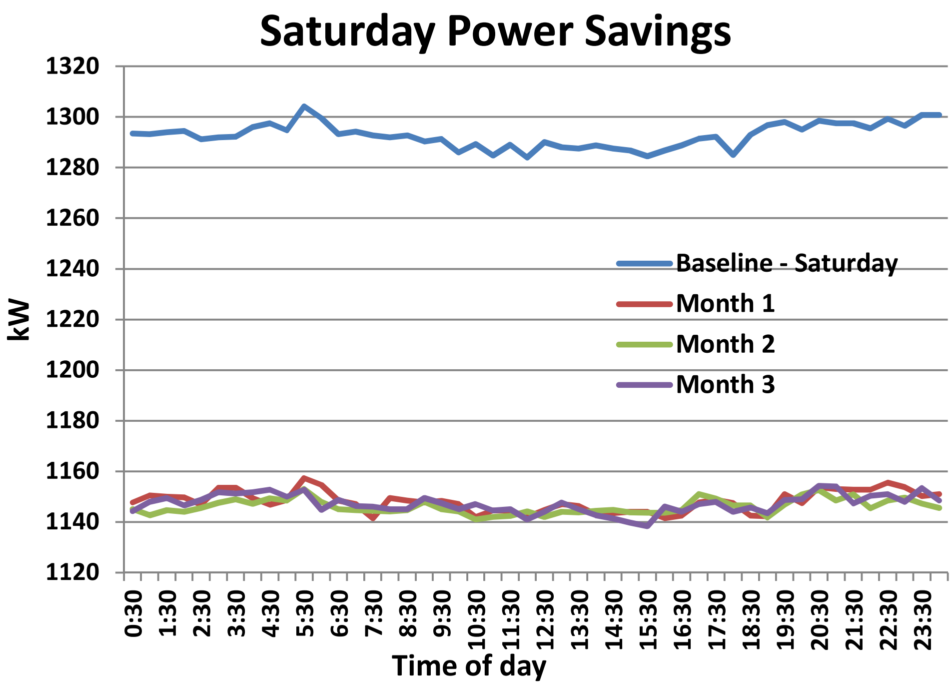

Figure 41: Saturday power savings of three months.

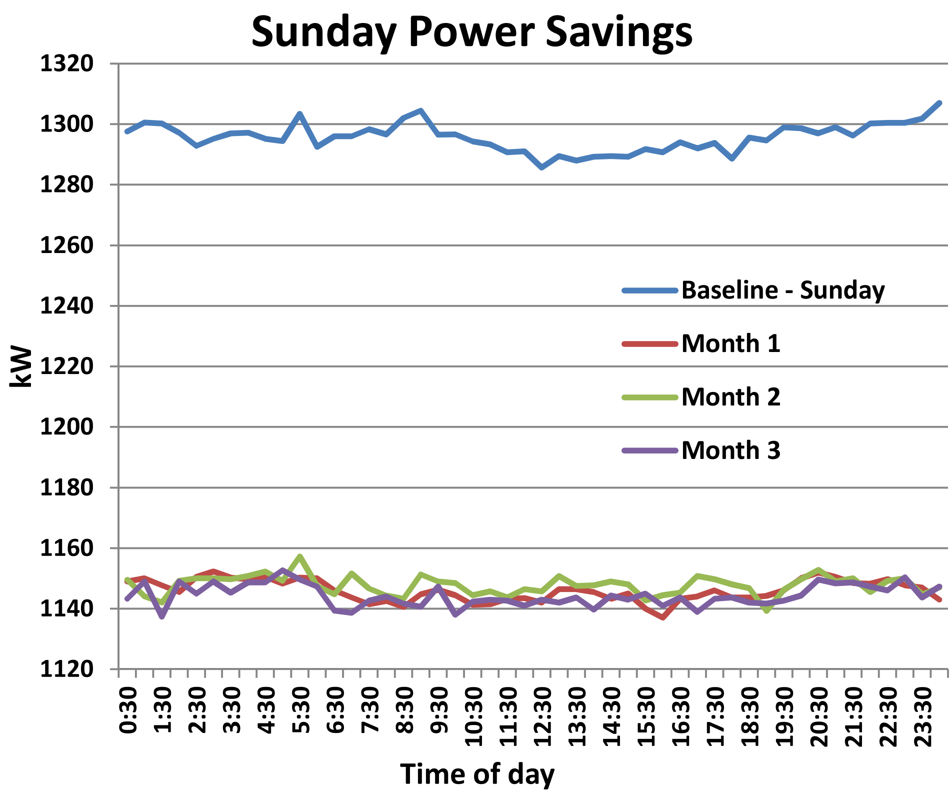

Figure 42: Sunday power savings of three months

The averaged actual power savings over the three-month period is presented in Table 19 representing weekdays, Saturdays and Sundays. The power reduction at the 20° IGV setting that is possible is 176 kW compared to the 186 kW that was simulated. This results in a 13.4% reduction of the power of the fans. The energy savings and cost implications will be discussed in the next chapter of this document.

Table 19: Average power savings for a weekday, Saturday and Sunday

Time	Average Weekday saving [kW]	Average Saturday saving [kW]	Average Sunday saving [kW]
00:30	148.58	147.83	150.32
01:00	149.40	146.22	152.93
01:30	151.71	145.97	157.84
02:00	151.26	147.75	149.28
02:30	149.99	144.22	144.30
03:00	147.76	141.05	144.78
03:30	146.43	141.00	148.56
04:00	150.23	146.52	147.48
04:30	146.61	147.87	144.73
05:00	148.00	145.70	144.34
05:30	145.22	149.92	151.01
06:00	147.07	150.36	144.22
06:30	149.99	145.83	152.64
07:00	152.47	148.27	151.31
07:30	153.13	148.78	154.72
08:00	148.29	145.77	153.06
08:30	145.47	146.63	160.17
09:00	143.42	141.94	158.92
09:30	145.95	144.39	148.97
10:00	147.25	140.60	153.00
10:30	142.46	145.92	151.64
11:00	144.09	141.08	149.92
11:30	142.03	145.03	147.53
12:00	140.98	141.60	147.33
12:30	141.48	146.42	142.02
13:00	137.64	141.78	142.98
13:30	141.30	142.48	142.11
14:00	141.08	145.39	144.89
14:30	139.67	144.29	143.87
15:00	139.21	144.26	143.87
15:30	140.40	142.52	149.17
16:00	139.54	143.05	149.92
16:30	139.88	145.05	149.94
17:00	139.07	142.92	147.42
17:30	140.57	143.60	147.44
18:00	141.97	138.97	143.46
18:30	139.14	148.08	151.43
19:00	148.45	154.29	152.88
19:30	144.75	149.18	154.03
20:00	145.83	145.90	150.57
20:30	139.55	144.94	145.53
21:00	145.38	145.70	149.72
21:30	146.95	147.21	147.14
22:00	148.47	146.01	153.17
22:30	142.10	147.62	152.07
23:00	147.12	146.05	151.04
23:30	145.99	150.49	156.66
00:00	147.66	152.42	161.22

5.4 CONCLUSION

From the tests and measurements that were taken on the MVFs it was shown that significant power reduction of the system was possible. This indicated that an EE strategy could be implemented on MVFs in deep level mines and that this can be done within the constraints of the environmental regulations of the mine.

The possible energy savings, the capital that was invested and the impact on the operational cost are discussed in the next chapter of this document. A business case will also be developed and discussed and the effect it has on the electrical cost of the MVFs of the mine.

CHAPTER 6 – FINANCIAL ANALYSIS

This chapter provides a financial analysis of the EE strategy that was implemented, and discusses capital and operational expenditure and the cost saving that can be achieved. This chapter concludes with a business case being developed.

6.1 INTRODUCTION

The cost of electricity is increased yearly and therefore the operating costs of the MVFs increases annually. Operating costs can be reduced by reducing the electrical energy usage on these fans. By controlling the IGVs on these fans significant savings can be achieved as calculated from the previous chapter.

This chapter addresses the cost savings that were achieved as well as the capital investment and operational costs required for the IGVs. A simple payback of the investment is also determined and shows that this can be a feasible investment.

6.2 CAPITAL INVESTMENT AND OPERATIONAL COSTS OF THE SYSTEM

The IGV control system that was implemented has two cost components, namely the initial capital investment and the operational expenditure. Details of both are given.

Cost of initial capital investment of the IGVs

The total capital cost of the improved IGVs was R 960 000 for both of the fans. This included all the mechanical and electrical components as well as the complete installation. Details of the costing are presented in Table 20. The next section describes the operational costs that are involved with the IGVs.

Table 20: Capital cost of IGVs

Description	Quantity	Unit cost	Total Cost
Mechanical hardware			
Inlet guide vanes	2	R 300 000	R 600 000
Electrical hardware			
Actuator with gearbox	2	R 80 000	R 160 000
Power meters	2	R 15 000	R 30 000
PLC + instrumentation	1	R 30 000	R 30 000
Installation			
Mechanical installation cost	2	R 60 000	R 120 000
Electrical installation cost	2	R 10 000	R 20 000
Total			**R 960 000**

Operational costs of the IGVs

The IGVs will operate in a corrosive and abrasive environment. Previous IGV designs and installations have been subject to loss of functionality and even outright failure, which could have been prevented by a schedule of routine maintenance and inspection.

In order to prevent costly asset damage, poor electrical savings, and the costly downtime in the event of a major failure, it is advised that the mine enters into a regular schedule of maintenance after installation. A full service must be done every 3 months. Furthermore a thorough visual inspection should be done every month, as this is the current practice.

During a full service, a comprehensive procedure takes place whereby the hub and internal parts are inspected, cleaned and re-greased, before being reassembled. The IGV blades and support stays are also checked for rust, scale, wear and other surface defects, and are recoated or treated as required.

A typical work breakdown structure for the maintenance will be:

1. Inspect blades, hub, support stays, vortex breaker and actuator arm for corrosion and wear.
2. Inspect external pins for corrosion and play. Replace if necessary.
3. Inspect bushes for play.
4. Remove vortex breaker (item 16). Replace bolts if necessary.
5. Remove rear cover plate (item 12).
6. Inspect shaft area at cover plate bush.
7. Inspect shaft (item 6).
8. Check that no moisture has entered into the hub.
9. Remove spider ring (item 7) and inspect all ball pins (item 11). Replace if necessary.
10. Inspect operating channel and report on wear.
11. Inspect main drive shaft keys and key-ways at the spider ring fit
12. Ensure no moisture / dirt has entered at front cover plate shaft bush.
13. Re-grease and re-fit all items removed in tasks 3-8.
14. Re-fit rear cover plate and vortex breaker.

The total cost for maintenance on both fans per year is R 120 000 and is presented in Table 21.

Table 21: Annual operational costs

Description	Quantity	Unit cost	Total Cost
Maintenance			
Services maintenance and inspections for a year	8	R 15 000	R 120 000
Total			**R 120 000**

This equates to a total cost of R 1 080 000 for the first year. The savings achieved with the IGVs are discussed in the next section of the document.

6.3 COST SAVINGS ACHIEVED

The energy usage of the fans was measured for 6 months to determine the actual energy savings of the intervention. The energy savings were determined from the following equation.

$$E_{Savings} = E_{Baseline} - E_{Actual} \quad (9)$$

Where, E is the electrical energy in kWh. Each half hourly logged kWh value is subtracted from the corresponding half hourly baseline kWh value. By using Eskom MF tariff the actual cost saving was determined. The total cost saving for the six months was R 808 955. The savings of the six months is presented in

Table 23. The MF tariff that was used to determine the cost saving for the first four months is presented in Table 22. The next year's MF tariff was used for the last two months and is presented in chapter 4 in Table 11.

Table 22: 2014/2015 Megaflex tariff [c/kWh]

Megaflex - Active energy charge	High-demand season (June – August) [c/kWh]	Low-demand season (September – May) [c/kWh]
Peak	243.6	86.6
Standard	92.2	64.5
Off-peak	62.1	46.7

Table 23: Cost savings of the first six months

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total
00:30	R 2 126	R 2 156	R 1 822	R 2 074	R 2 606	R 2 823	R 13 607
01:00	R 2 121	R 2 213	R 1 804	R 2 055	R 2 694	R 2 900	R 13 788
01:30	R 2 161	R 2 235	R 1 833	R 2 086	R 2 708	R 2 825	R 13 847
02:00	R 2 147	R 2 193	R 1 840	R 2 077	R 2 731	R 2 835	R 13 824
02:30	R 2 139	R 2 147	R 1 809	R 2 051	R 2 775	R 2 927	R 13 848
03:00	R 2 118	R 2 117	R 1 780	R 2 060	R 2 785	R 2 903	R 13 762
03:30	R 2 101	R 2 113	R 1 778	R 2 002	R 2 757	R 2 877	R 13 628
04:00	R 2 152	R 2 165	R 1 817	R 2 040	R 2 778	R 3 030	R 13 982
04:30	R 2 129	R 2 116	R 1 775	R 2 010	R 2 779	R 3 013	R 13 822
05:00	R 2 092	R 2 143	R 1 808	R 2 027	R 2 577	R 2 826	R 13 472
05:30	R 2 093	R 2 104	R 1 820	R 1 995	R 2 718	R 2 919	R 13 649
06:00	R 2 039	R 2 133	R 1 806	R 1 885	R 2 589	R 2 833	R 13 284
06:30	R 2 634	R 2 802	R 2 296	R 2 448	R 3 395	R 3 530	R 17 105
07:00	R 2 701	R 2 721	R 2 279	R 2 450	R 3 282	R 3 777	R 17 209
07:30	R 3 516	R 3 633	R 2 927	R 3 209	R 4 285	R 4 611	R 22 181
08:00	R 3 406	R 3 545	R 2 837	R 3 159	R 4 106	R 4 514	R 21 567
08:30	R 3 391	R 3 487	R 2 793	R 3 151	R 4 145	R 4 723	R 21 690
09:00	R 3 436	R 3 420	R 2 759	R 3 148	R 4 093	R 4 730	R 21 585
09:30	R 3 435	R 3 569	R 2 788	R 3 069	R 4 082	R 4 725	R 21 668
10:00	R 3 492	R 3 534	R 2 958	R 3 225	R 4 013	R 4 685	R 21 907
10:30	R 2 776	R 2 792	R 2 228	R 2 562	R 3 118	R 3 573	R 17 050
11:00	R 2 804	R 2 789	R 2 227	R 2 643	R 3 155	R 3 856	R 17 474
11:30	R 2 767	R 2 766	R 2 308	R 2 642	R 3 140	R 3 571	R 17 194
12:00	R 2 726	R 2 731	R 2 306	R 2 606	R 3 108	R 3 677	R 17 153
12:30	R 2 624	R 2 624	R 2 235	R 2 447	R 2 993	R 3 498	R 16 421
13:00	R 2 579	R 2 547	R 2 176	R 2 388	R 3 062	R 3 455	R 16 206
13:30	R 2 621	R 2 609	R 2 225	R 2 443	R 3 112	R 3 393	R 16 402
14:00	R 2 636	R 2 597	R 2 240	R 2 440	R 3 092	R 3 317	R 16 322
14:30	R 2 637	R 2 531	R 2 233	R 2 420	R 3 073	R 3 359	R 16 254
15:00	R 2 615	R 2 556	R 2 212	R 2 418	R 3 078	R 3 235	R 16 114
15:30	R 2 624	R 2 628	R 2 201	R 2 441	R 2 821	R 3 236	R 15 952
16:00	R 2 638	R 2 606	R 2 184	R 2 454	R 3 085	R 3 584	R 16 550
16:30	R 2 638	R 2 626	R 2 188	R 2 423	R 3 110	R 3 629	R 16 614
17:00	R 2 633	R 2 551	R 2 204	R 2 486	R 3 318	R 3 583	R 16 775
17:30	R 2 630	R 2 625	R 2 203	R 2 445	R 3 109	R 3 331	R 16 343
18:00	R 2 524	R 2 618	R 2 235	R 2 489	R 3 274	R 3 440	R 16 579
18:30	R 3 318	R 3 399	R 2 920	R 3 226	R 4 541	R 4 586	R 21 990
19:00	R 3 591	R 3 688	R 3 062	R 3 293	R 4 572	R 4 734	R 22 940
19:30	R 3 539	R 3 572	R 2 989	R 3 192	R 4 549	R 4 719	R 22 561
20:00	R 3 557	R 3 526	R 3 029	R 3 276	R 4 584	R 4 695	R 22 666
20:30	R 2 609	R 2 602	R 2 202	R 2 445	R 3 485	R 3 609	R 16 952
21:00	R 2 675	R 2 727	R 2 283	R 2 532	R 3 503	R 3 707	R 17 426
21:30	R 2 713	R 2 714	R 2 315	R 2 531	R 3 537	R 3 704	R 17 513
22:00	R 2 710	R 2 797	R 2 326	R 2 580	R 3 538	R 3 681	R 17 633
22:30	R 2 067	R 2 120	R 1 733	R 1 996	R 2 758	R 2 920	R 13 594
23:00	R 2 116	R 2 150	R 1 791	R 2 042	R 2 758	R 2 870	R 13 728
23:30	R 2 123	R 2 183	R 1 774	R 2 050	R 2 775	R 2 884	R 13 789
00:00	R 2 066	R 2 133	R 1 752	R 2 043	R 2 624	R 2 716	R 13 334
Total	R 126 986	R 128 354	R 107 108	R 119 171	R 156 770	R 170 567	R 808 955

A significant increase in the cost saving for the last two months is noted because of the higher MF tariff being used. The next section of the document will give the business case for the study.

6.4 BUSINESS CASE

From the savings that were determined in the previous section the annual electrical cost savings was estimated to be R 1 617 910. By using this annual cost saving with an annual increase of 9% which is taken from chapter 2, the simple payback of this IGV implementation is just over 8 months. A summary of the cash flow with the payback is presented in Table 24.

Table 24: Payback and cash flow summary

Payback				
	year 1	**year 2**	**year 3**	**year 4**
Project Costs:				
Total project cost	R1 080 000			
Client Cash Flows:				
Tariff Escalation	0.0%	9.0%	*9.0%*	*9.0%*
Electricity cost saving		R 1 617 910	*R 1 763 521*	*R 1 922 238*
Net cash flow	*-R 1 080 000*	*R 1 617 910*	*R 1 763 521*	*R 1 922 238*
Cumulative cash flow	*-R 1 080 000*	*R 537 910*	*R 2 301 431*	*R 4 223 669*

6.5 CONCLUSION

The implementation cost of the IGV system was R 960 000 and the operational cost of the IGVs will be R 120 000 per year. This is expensive but with a potential annual electrical cost saving of about R 1 617 910 this is very feasible for a mine to implement as the investment cost can quickly be recouped.

Since the simple payback period of the system is less than a year this EE strategy should be considered by deep level mines for implementation.

CHAPTER 7 – CLOSURE

This chapter provides a summary and conclusion of the dissertation, and recommendations for future work is also summarised.

7.1 SUMMARY AND CONCLUSION

The purpose of this research was to investigate an energy reduction strategy by controlling the IGVs on the MVFs of a deep level platinum mine. This had to be achieved without compromising the safety of the mine workers by ventilating the mine to the required standard of $233m^3/s$.

A case study mine was selected and the necessary information was gathered from the MFVs characteristics, inspections and available energy data and it was found that there is a significant opportunity to reduce the electricity cost on the fans by controlling the IGVs since there was no EE strategy in place. The IGVs that were installed could not be controlled due to mechanical failures on them.

New improved IGVs were introduced to the MFVs to allow for control of the IGVs. This was necessary in order to avoid further failures on them. A simulation was done on the fans with the IGVs and it was determined that the mine can still be ventilated with the IGVs operating a 16° angle from the fully open position. This results in a volume and power reduction of 6% and 16% respectively, which will lead to significant cost reductions on the MFVs electricity costs.

From the actual measurements that were taken according to the ISO 5802:2001 industrial fan testing standard on the MFVs, it was determined that the IGVs can operate at a 20° angle from the fully open position. At this point the mine is still ventilated above the required volume of $233m^3/s$. At this IGV setting the fan efficiency reduced from 70% to 65%. The actual reduction in volume and power at this IGV setting was found to be 9% and 13.4% respectively. This resulted in an annual electricity cost saving of R 1 617 910.

With a capital cost of R 960 000 and an annual operational cost of R 120 000 per year the IGVs resulted in a payback of less than a year. This proves that significant savings are achievable on the electricity cost of a deep level platinum mine by controlling the IGVs.

7.2 RECOMMENDATIONS FOR FUTURE WORK

Due to the fans currently operating at the low efficiency which is evident from the results, significant additional savings can be achieved by increasing this efficiency. The following areas might require further attention to increase the savings:

- To increase the resistance of the mine, thereby increasing the system pressure for the fan to operate as close as possible to its designed operating point. This can be achieved by optimising the underground working areas of a deep level mine through sealing work. This will increase the system efficiency and further clipping could be possible for even further savings.
- The investigation into increasing the efficiency of the inefficient impellers. This can be achieved by a new design or by selection of other impellers that are suitable for the application. Further clipping can be possible with the increased efficiency to give significant savings.
- By installing VSDs on the fans and operating the fan at the highest efficiency point with the guide vanes (fully open). The fan can then be speed down with the VSD to the same operating point. This will become very feasible once the price of a VSD drops.
- The investigation of replacing the old inefficient fans with more efficient ones. This could result in further savings but it will be expensive. The installation of this should also be investigated as the mine cannot operate without the fans, except over non-operational periods, which is not longer than a week during Christmas time.

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APPENDIX A – IGV COMPONENTS

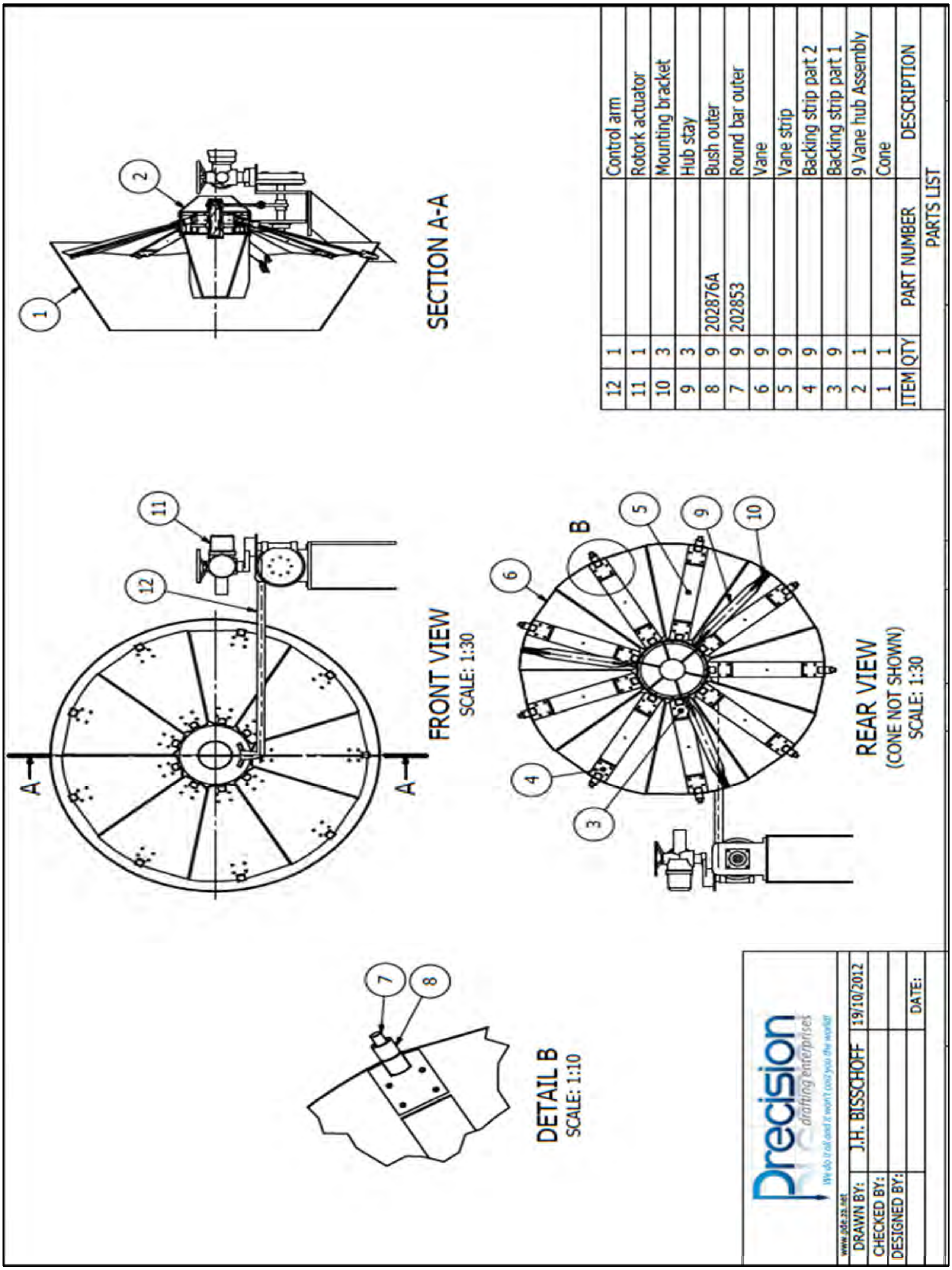


Figure 43: Components of the IGV

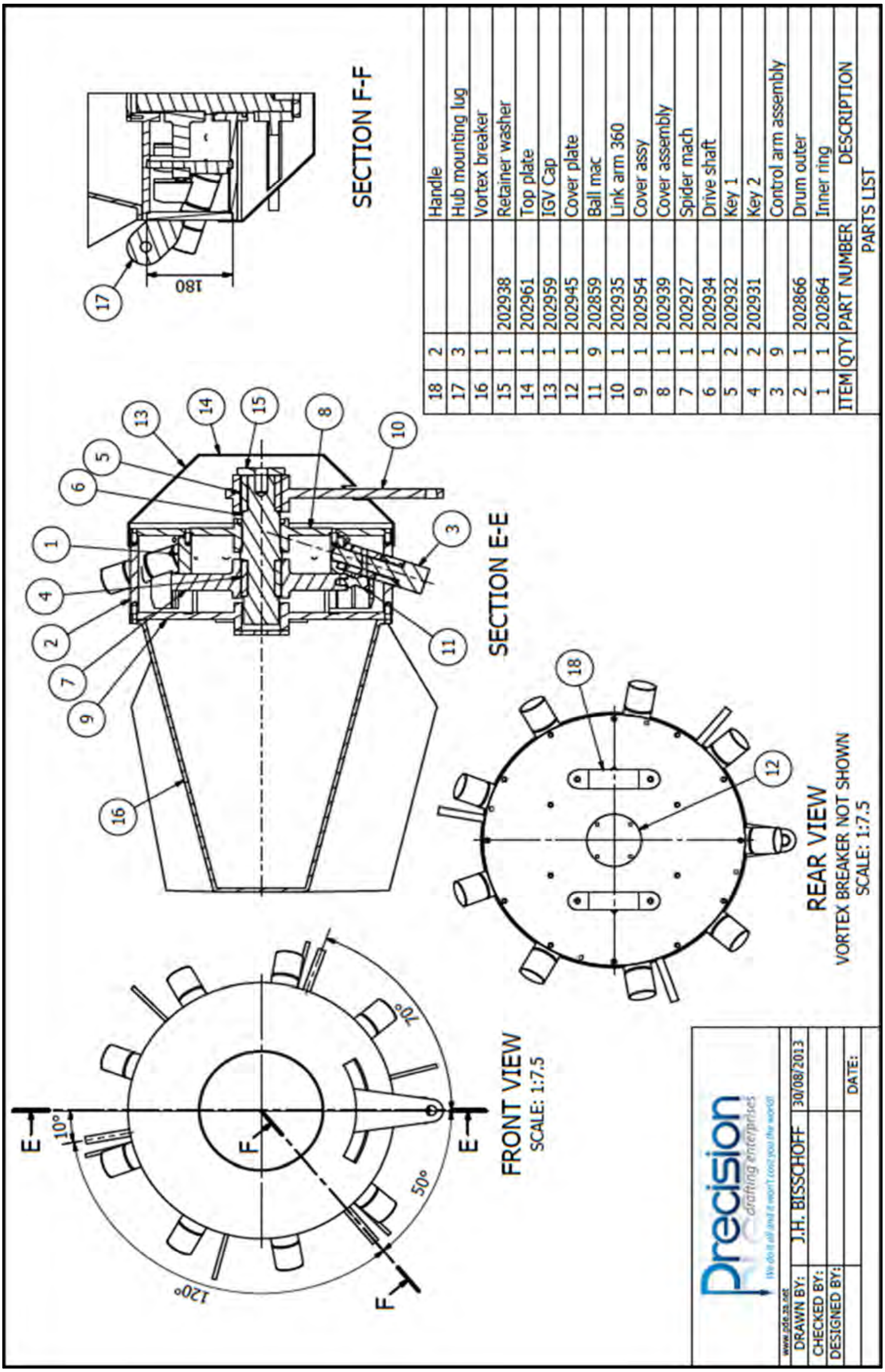
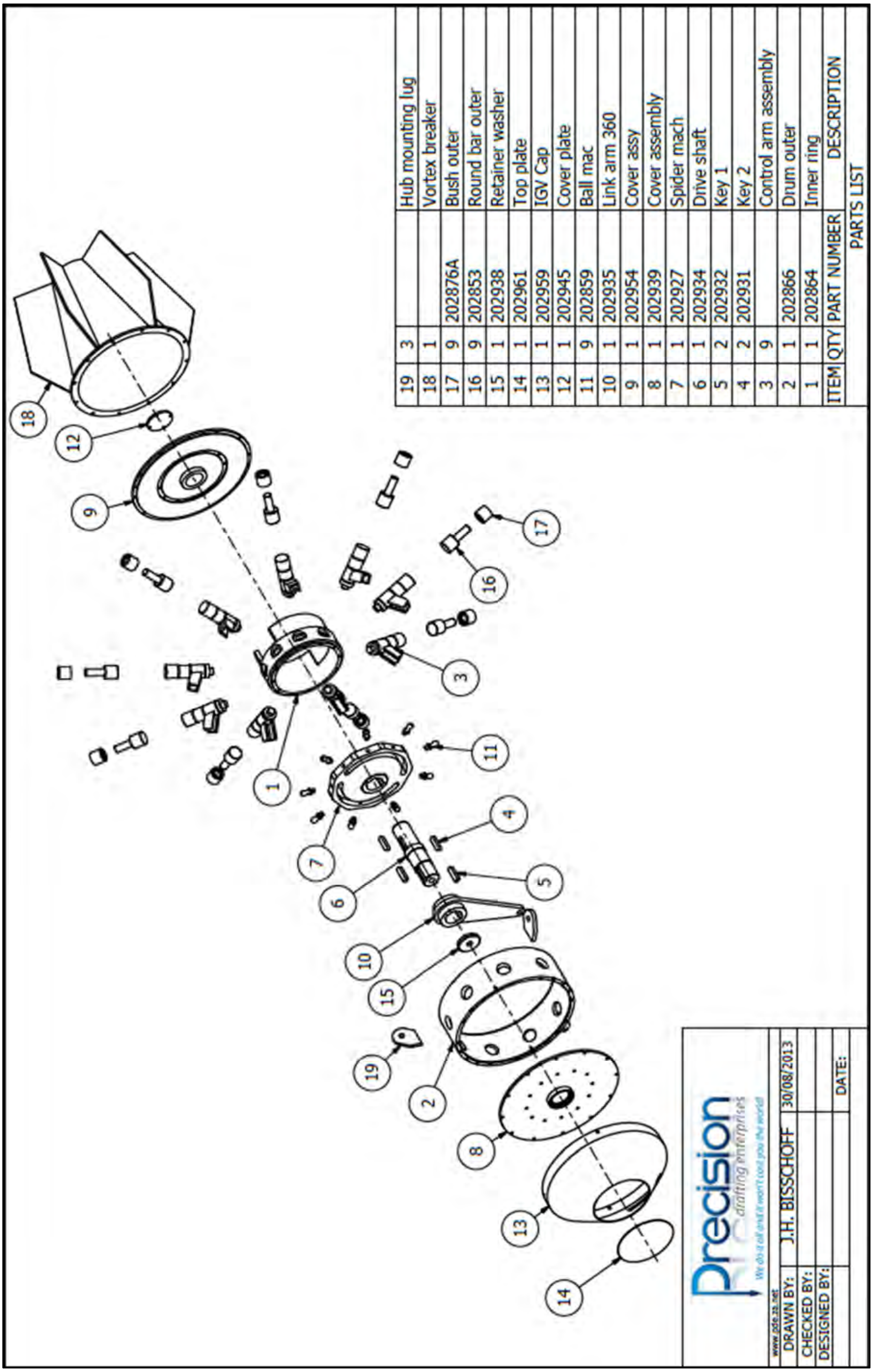


Figure 44: Components of the IGV hub.



ITEM	QTY	PART NUMBER	DESCRIPTION
19	3		Hub mounting lug
18	1		Vortex breaker
17	9	202876A	Bush outer
16	9	202853	Round bar outer
15	1	202938	Retainer washer
14	1	202961	Top plate
13	1	202959	IGV Cap
12	1	202945	Cover plate
11	9	202859	Ball mac
10	1	202935	Link arm 360
9	1	202954	Cover assy
8	1	202939	Cover assembly
7	1	202927	Spider mach
6	1	202934	Drive shaft
5	2	202932	Key 1
4	2	202931	Key 2
3	9		Control arm assembly
2	1	202866	Drum outer
1	1	202864	Inner ring

PARTS LIST

Figure 45: Exploded view of the hub.

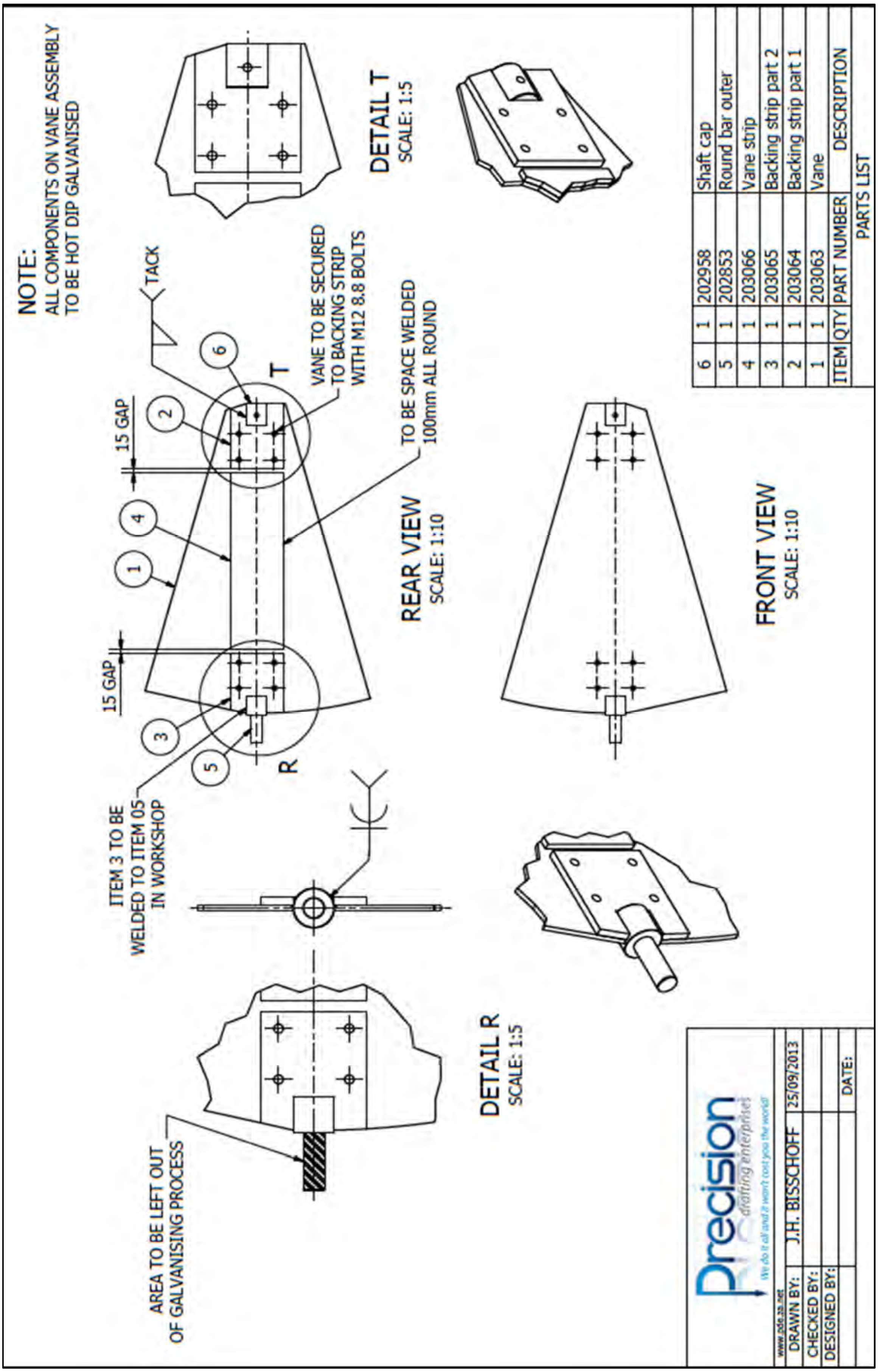


Figure 46: General arrangement of the vanes:

APPENDIX B – FAN CURVES, EFFICIENCY CURVES AND POWER CURVES

APPENDIX B – FAN CURVES, EFFICIENCY CURVES AND POWER CURVES

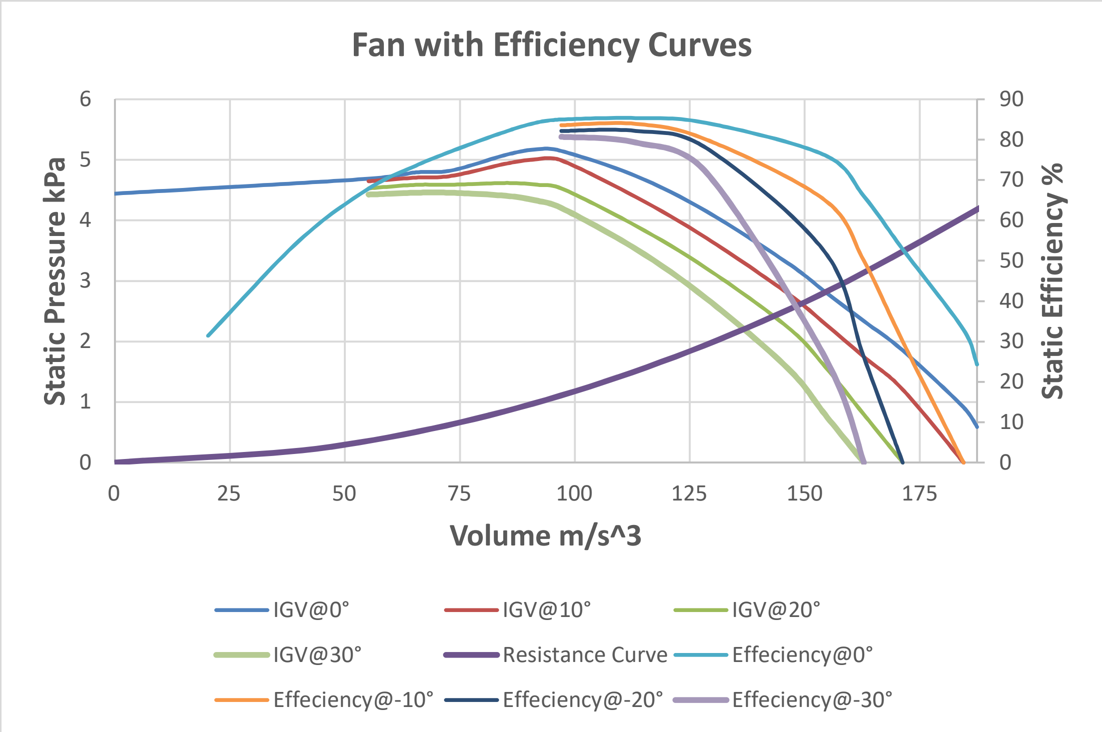


Figure 47: Fan curves with the efficiency curves of mine A

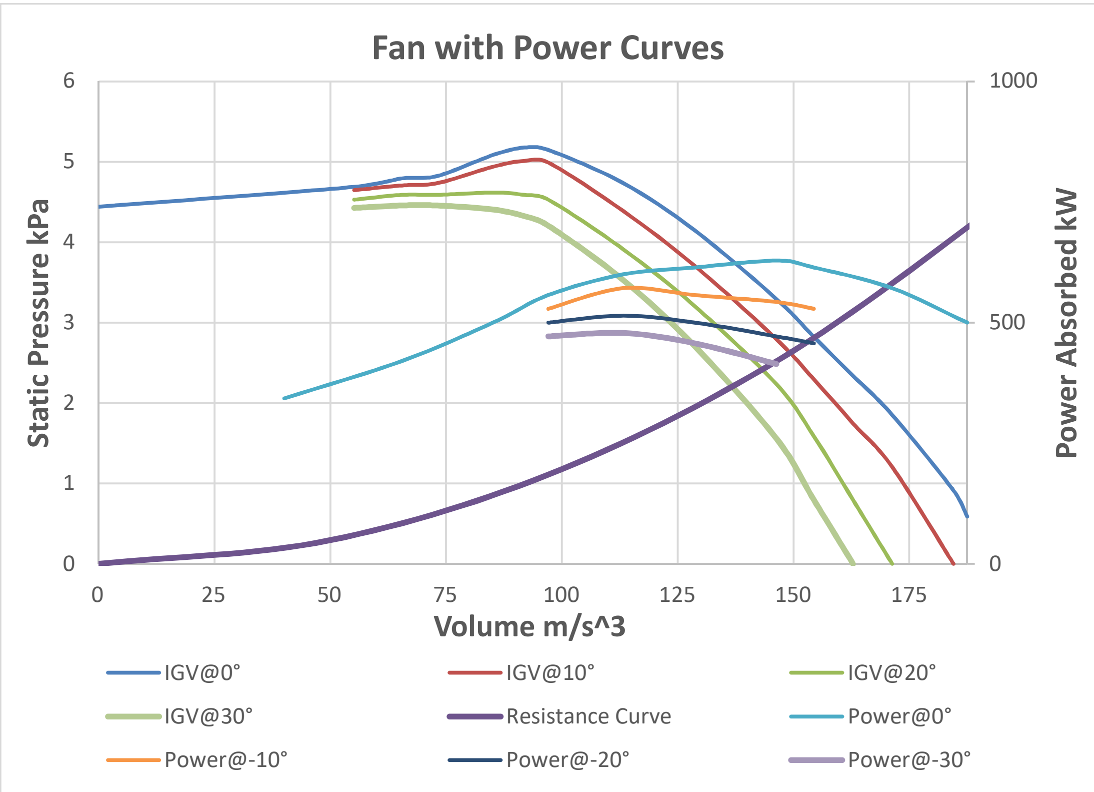


Figure 48: Fan curves with the power curves of mine A

APPENDIX C – INSTALLATION REPORTS

Fan 1

BBE Energy (Pty)Ltd MINING AND INDUSTRIAL ENERGY SPECIALISTS

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CONTENTS

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T: +27 11 706 9800 F: +27 11 706 6931 E: bbe@bbe.co.za PO Box 786012 Sandton 2146 South Africa www.bbe.co.za

1. Saturday 08/02/2014

1. The IGV hubs, vane assemblies, actuator arms and actuator pedestals for both IGVs were delivered to the fan station on Saturday 08/02/2014
2. Contractors arrived on site at around 07:30 the Saturday 08/02/2014 for site induction, toolbox talks, daily task observation, tools inspection and risk assessment.
3. Fan1 was shut down and locked out by the mine according to the lockout procedure before arrival on site.
4. The fan access door was opened and work commenced at 08:30.
5. The old IGV (Hub stays, and hub) was stripped out.

Figure 1: Old IGV

6. Temporary lifting lugs were welded onto the drift for lifting of the hub and the vanes.
7. The new hub was safely lifted into the drift and centred correctly.
8. The hub stays were bolted to the hub and welded in place to the drift cone.
9. The vanes and bushes were pre-assembled outside the drift.
10. Laser alignment was performed to determine where to cut the holes for the outer bushes.
11. The holes were cut and ground clean by an angle grinder in preparation for welding of the outer bushes.

Figure 2: Hole for new IGV

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12. The vanes were carried safely into the drift and were tack welded onto the hub.

Figure 3: Alignment of the vanes

13. The outer bushes which then protruded through the holes were welded in place. Welding was done on the inside of the cone.
14. Each vane was then unbolted from its two backing strips, so that a full seam weld could be done to affix the hub-end backing plate to the hub bush.
15. The vortex breaker was bolted to the rear of the hub.

Figure 4: Vortex breaker bolted onto back of the hub

16. Vanes were then bolted in place with the correct dome-head caps.
17. The push rod (with elbow joint) was bolted onto the hub control arm and was cut to size over the actuator.
18. The control arm was attached to the actuator arm by another elbow joint and adjusted to achieve the correct stroke length.
19. The correct operation of the vanes with the actuator was tested.
20. The angle indicators were welded on and the vanes calibrated to 0° (fully open), 10°, 20° and 30° and 90° (fully closed).

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Figure 5: Angle indicators on the actuator

21. Mechanical and electrical stops were added to the actuator.
22. All debris was removed from the fan drift.
23. The installation of the new inlet guide vanes on fan 1 finished at 16:00.
24. The fan was started up by the electrician and vibration measurements were taken.
25. The work finished at about 16:30 the Saturday afternoon.

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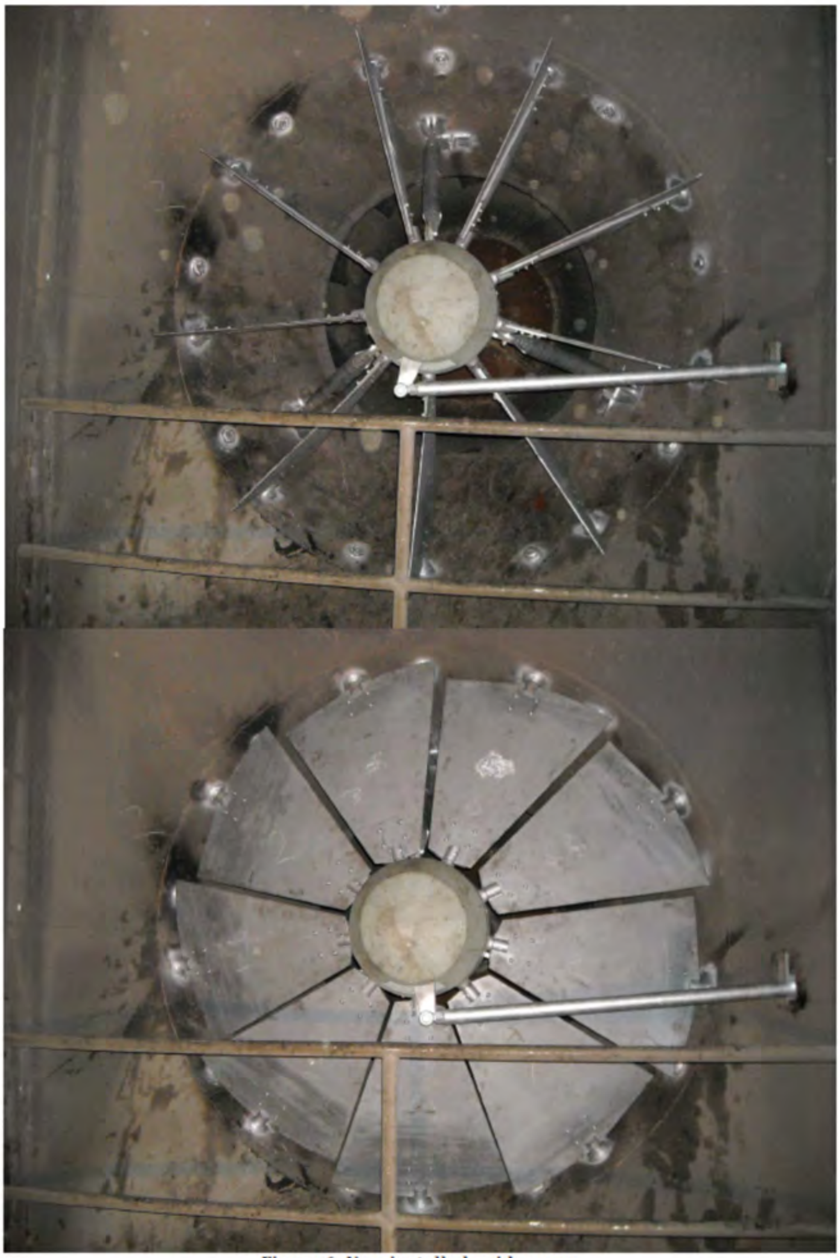

Figure 6: New installed guide vanes

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Fan 2

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1. Saturday 22/02/2014

1. The IGV hubs, vane assemblies, actuator arms and actuator pedestals for both IGVs were delivered to the fan station on Saturday 22/02/2014
2. Contractors arrived on site at around 07:30 the Saturday 22/02/2014 for site induction, toolbox talks, daily task observation, tools inspection and risk assessment.
3. Fan2 was shut down and locked out by the mine according to the lockout procedure before arrival on site.
4. The fan access door was opened and work commenced at 08:30.
5. The old IGV (Hub stays, and hub) was stripped out.
6. Temporary lifting lugs were welded onto the drift for lifting of the hub and the vanes.
7. The new hub was safely lifted into the drift and centred correctly.

Figure 1: Alignment of the hub and the vanes

8. The hub stays were bolted to the hub and welded in place to the drift cone.
9. The vanes and bushes were pre-assembled outside the drift.
10. Laser alignment was performed to determine where to cut the holes for the outer bushes.
11. The holes were cut and ground clean by an angle grinder in preparation for welding of the outer bushes.
12. The vanes were carried safely into the drift and were tack welded onto the hub.
13. The outer bushes which then protruded through the holes were welded in place. Welding was done on the inside of the cone.

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Figure 2: Outer bush

14. Each vane was then unbolted from its two backing strips, so that a full seam weld could be done to affix the hub-end backing plate to the hub bush.
15. The vortex breaker was bolted to the rear of the hub.
16. Vanes were then bolted in place with the correct dome-head caps.
17. The push rod (with elbow joint) was bolted onto the hub control arm and was cut to size over the actuator.
18. The control arm was attached to the actuator arm by another elbow joint and adjusted to achieve the correct stroke length.
19. The correct operation of the vanes with the actuator was tested.
20. The angle indicators were welded on and the vanes calibrated to 0° (fully open), 10°, 20° and 30° and 90° (fully closed).

Figure 3: Calibration of the vanes

21. Mechanical and electrical stops were added to the actuator.
22. All debris was removed from the fan drift.
23. The installation of the new inlet guide vanes on fan 2 finished at 16:00.

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24. The fan was started up by the electrician and vibration measurements were taken.
25. The work finished at about 16:30 the Saturday afternoon.

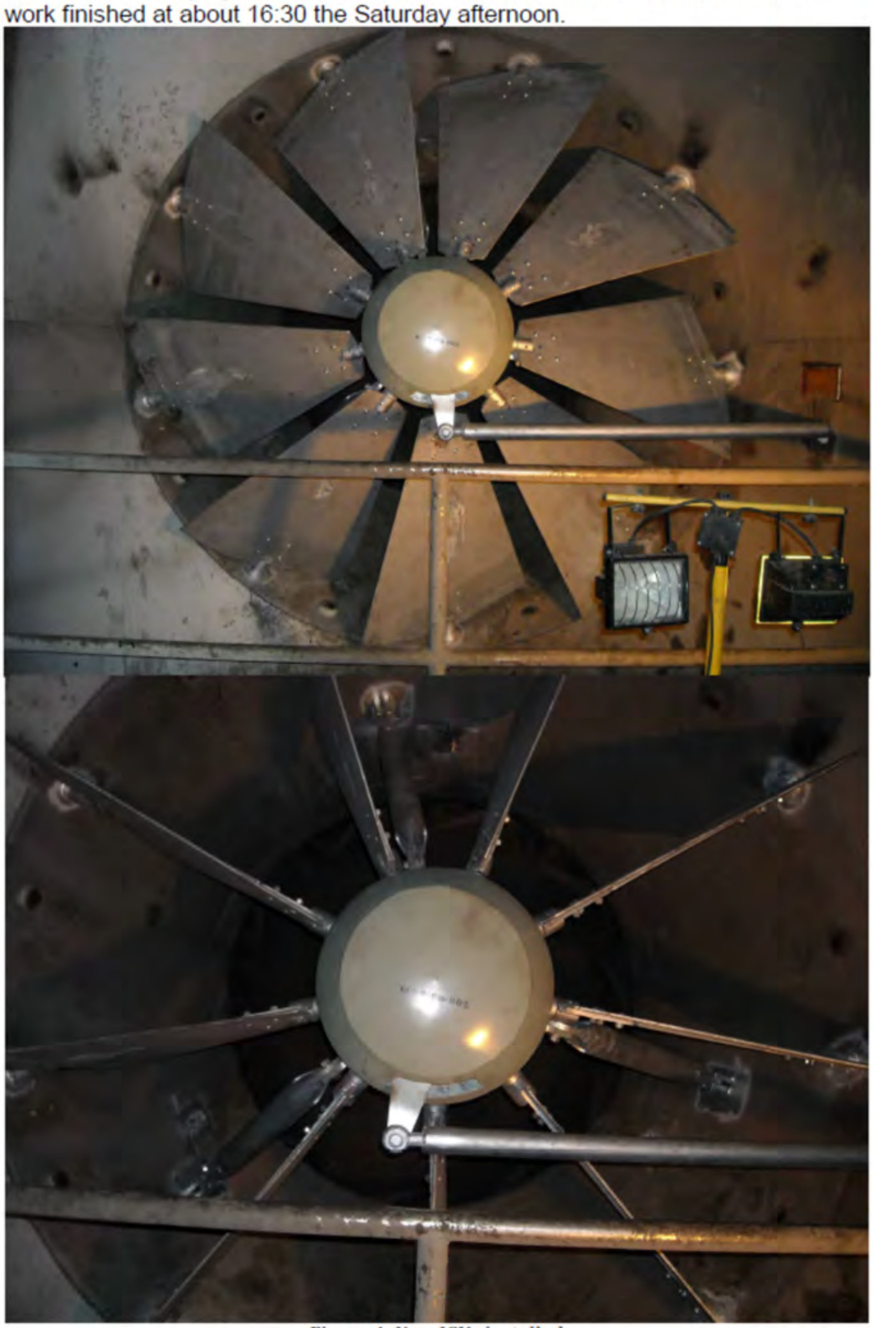

Figure 4: New IGVs installed

APPENDIX D – ADDITTIONAL GRAPHS

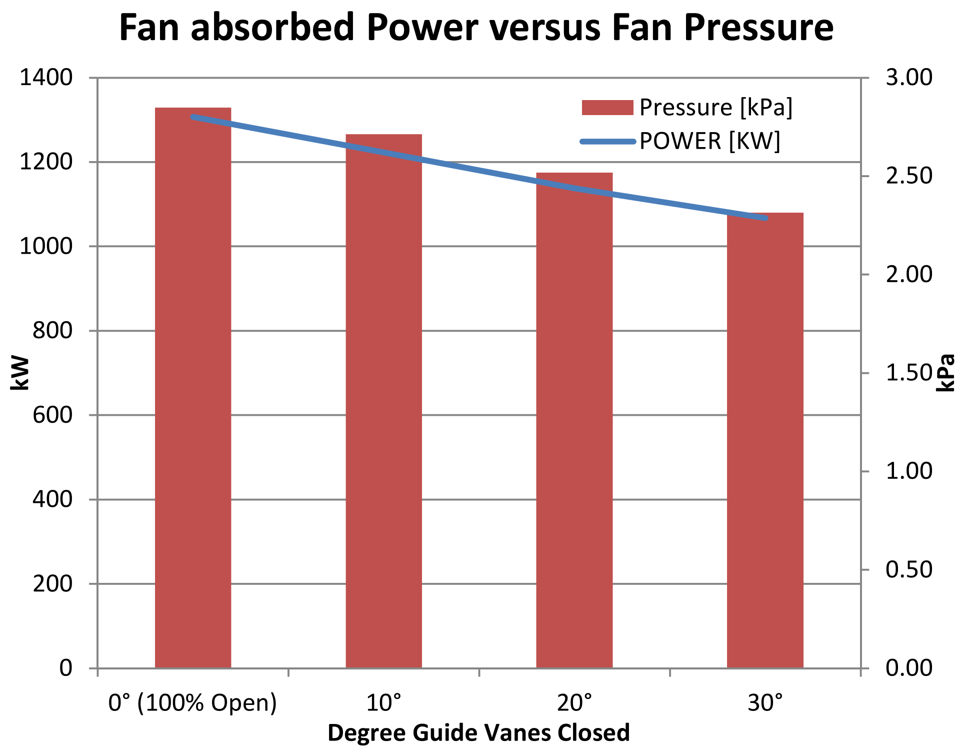

Figure 49: Fan absorbed power versus fan pressure.

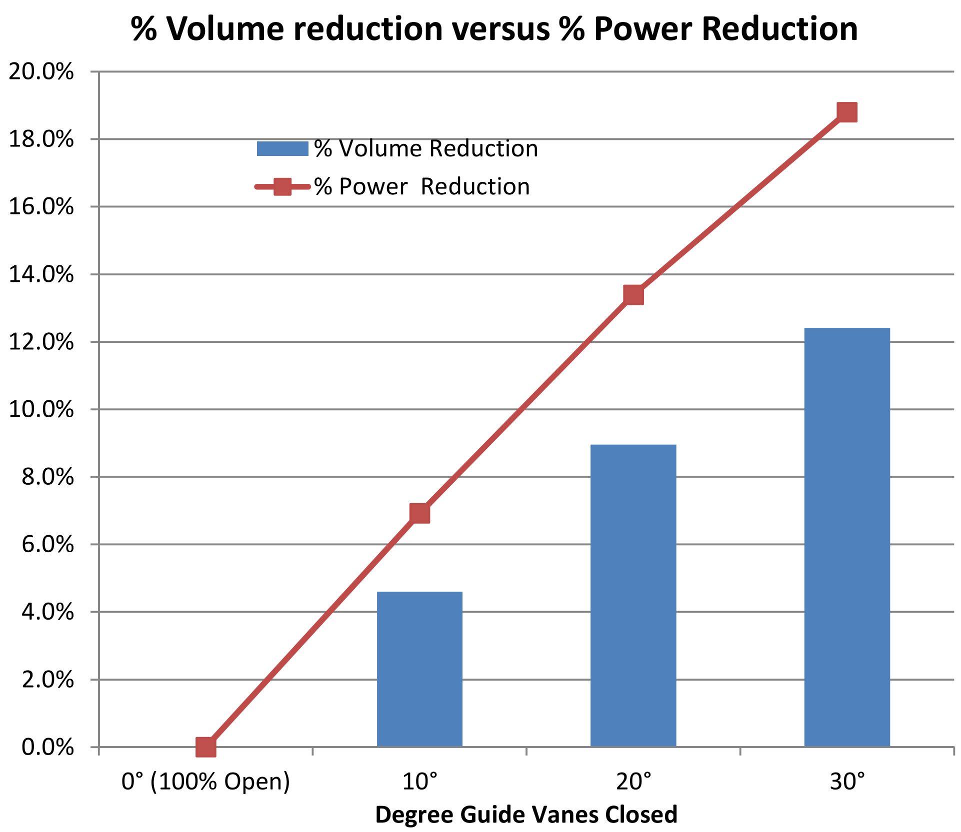

Figure 50: Percentage volume and power reduction

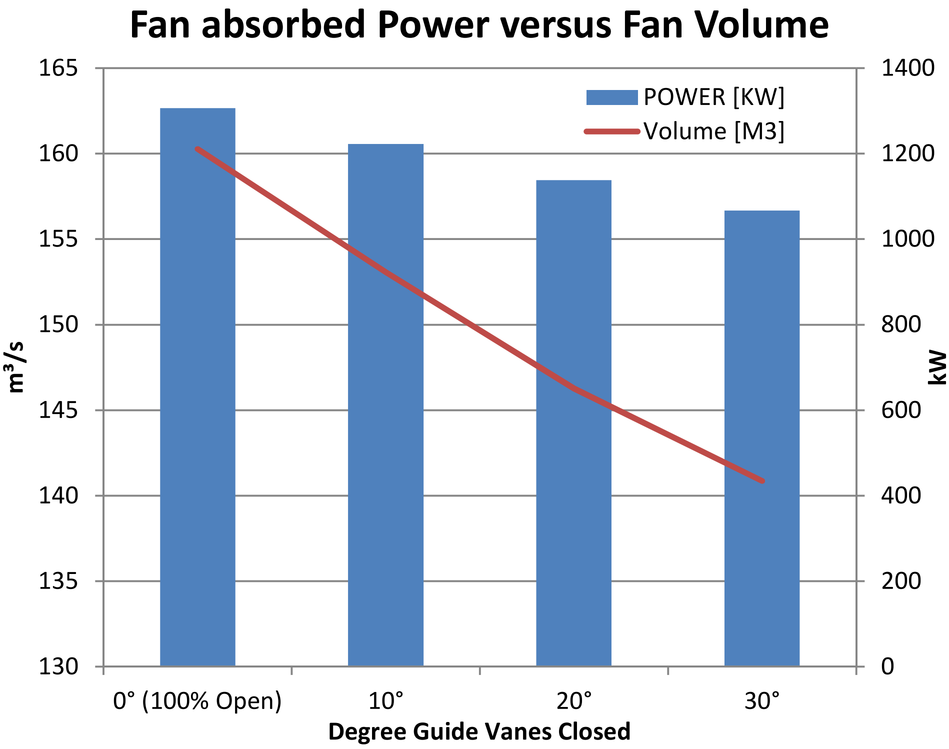

Figure 51: Fan absorbed power versus volume.

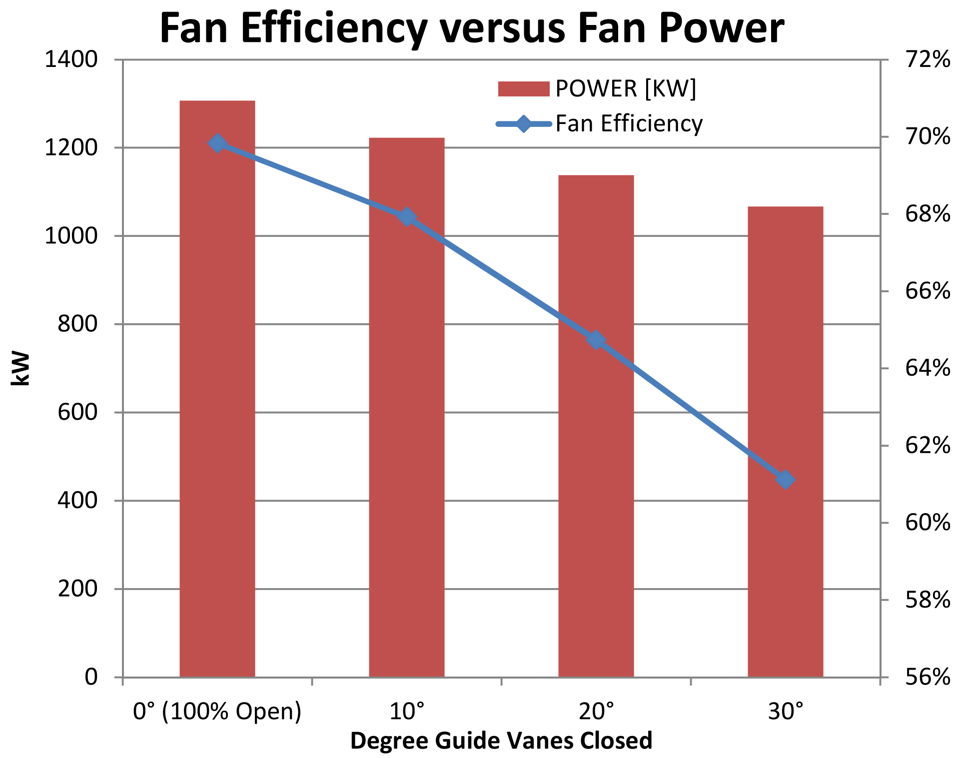

Figure 52: Reduction in fan power versus efficiency.