NEW VSD/VFD NATIONAL STANDARD FOR HAZARDOUS LOCATIONS AND THE IMPACT IT WILL HAVE ON THE MINING INDUSTRY

Henk Zwart

Electrical Engineering Consultant

1. SYNOPSIS

Latest technology has become more freely available and has been applied in industry at a rapid pace. As a result, hazards were not fully understood, and this introduced risks that can cause serious harm to people and the environment.

Variable Speed Drives/Variable Frequency Drives (VSD/VFD) have been used on various engineering technologies to improve mining efficiencies and mining methods that were previously difficult to achieve. The application of VSD/VFD's can be seen on conveyor drive systems, continuous mining machines, coal transporters and machines where precise speed control is required in underground hazardous locations.

Incidents were reported that people experience electrical shocks when touching two different machines in underground sections that use VSD/VFD technology. What caused this could not be explained at the time as the risks were not fully understood and this include spark ignition of gases.

As a result, the IEC conducted a comprehensive investigation into the use of VSD/VFD systems and produced an international IEC 61800-8 standard highlighting important factors to be considered for engineers to take note of when used.

However, when VFD/VSD systems are used in hazardous locations, spark ignition of dangerous gases could result in explosions. As no IEC or SANS standard is available for South Africa, a new VFD Working Committee was formed through SANS TC65 to write a standard for South Africa.

The result of the new SANS VFD standard will have an impact on the mining industry as the mitigation factors will entail the use of technology that could make the application of VFD/VSD systems impractical.

This paper covers the risks that VFD/VSD systems introduce when used on mining machinery. It is extremely important that the risks are clearly understood in order to mitigate these risks as the mitigation factors have to be effective thereby making the technology available for safe mining practices. One aspect of the risks is the possibility of electrocution. This risk is also covered in the paper as this risk poses a serious threat to the possible future use of this technology.

Final recommendation covered by the SANS VFD standard is where this technology could be impractical for use and the paper covers the recommendations in detail.

It is important to note that the intention of the SANS VFD standard is to mitigate spark ignition of gases in a hazardous location. This Standard is aimed at "making it safe"

when this type of technology is used and also to ensure engineers take the required steps in addressing risks that could be unknown to them.

Safe today, Safer tomorrow ……Coal mining.

2. HISTORIC MINING TECHNOLOGY

Technology used in the coal mining industry was historically based on Direct Current (DC) control. The control concepts were state of the art at the time of introducing the technology to the mining industry.

Simplistic concepts consisted out of;

- Main 550VAC/950VAC power supply feeding power from the section Power Centre (Transformer and switchgear)
- Power supplied to machine via trailing
- On board machine step down transformer
- DC control to motor
- DC motor power pack

DC controller technology was based on thyristor designs whereby the Alternating Current (AC) is switched thereby controlling the voltage to the DC motor as indicated in figures 1 and 2.

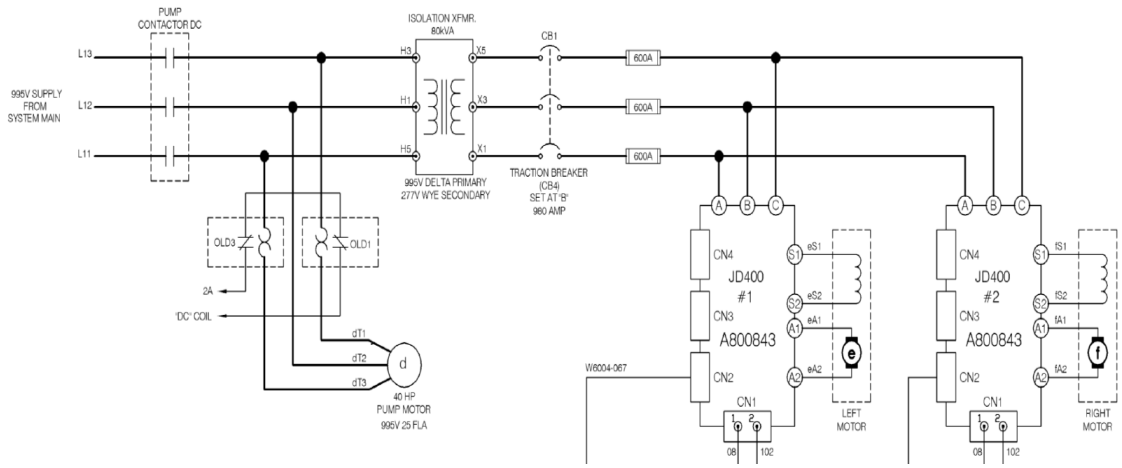

Figure 1. Basic DC Machine Control Diagram

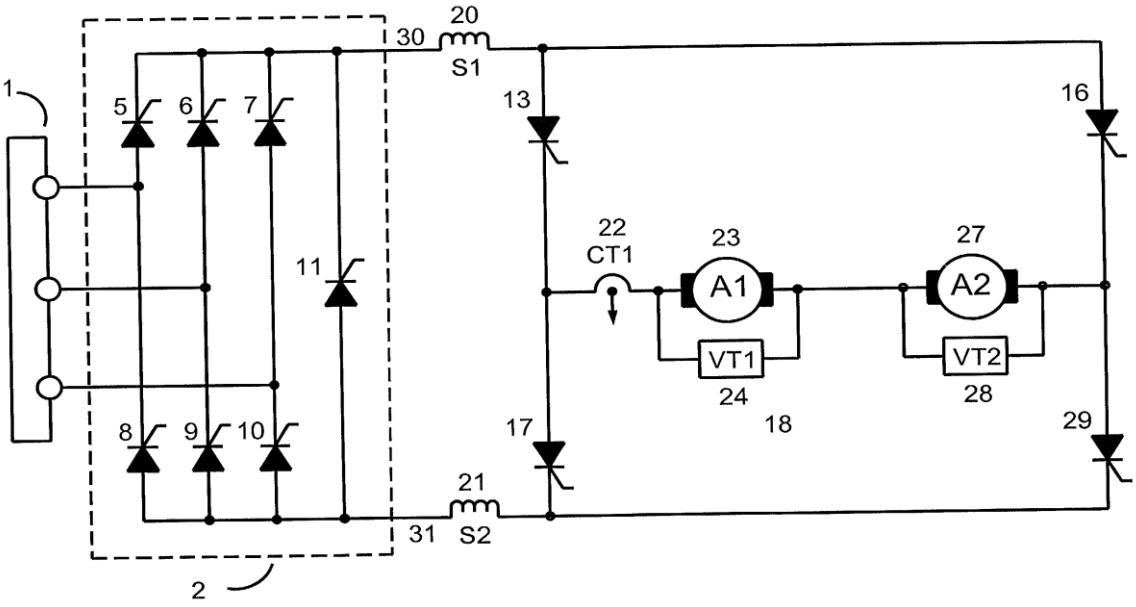

Figure 2. Basic Thyristor Control

Power and Torque of DC motors are therefore controlled and the concepts were applied on Coal Haulers, Continuous Miners etc.

Thyristor technology control the AC input by switching the positive and is automatically switched off during reverse polarity over the thyristor. Figure 3 indicated a basic thyristor control.

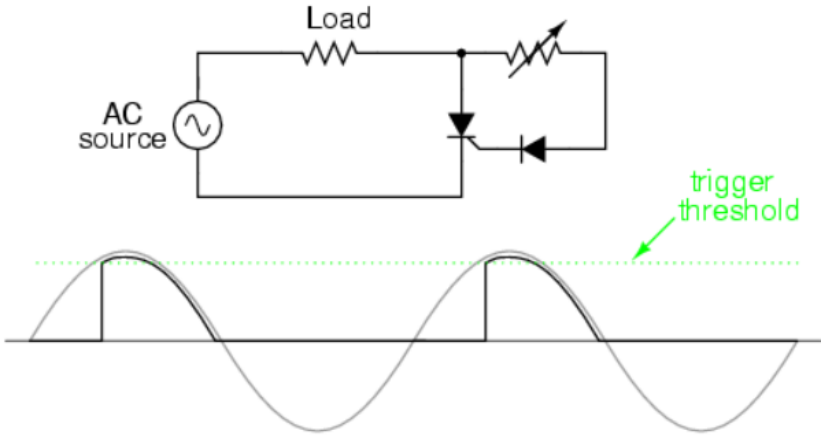

Figure 3. Basic Thyristor Switching Control Waveform

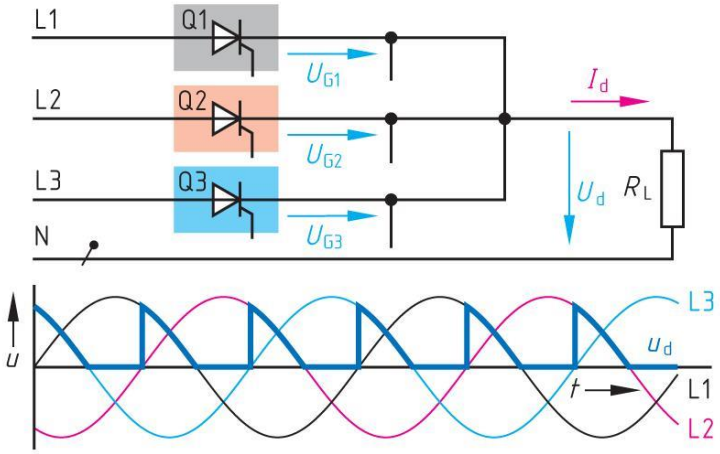

Figure 4. Simplistic 3 Phase DC Control

It is clear that the benefits of this control are very suitable due to the simplicity of the control system as indicated in figure 4.

As the fundamental frequency is based on 50Hz (f0=50Hz), switching harmonics are multiples of 50Hz (3^{rd} , 5^{th}, 7^{th}) and as a result, cable capacitance has no real influence.

All is not well seeing that this technology has a poor power factor and is therefore limited based on simplistic applications. Secondly, DC motors require good maintenance practices and when not maintained, will fail catastrophically. As expertise and competency of artisans become a problem, DC motors in general became a problem.

3. AC DRIVE SYSTEM

The real answer is to use AC motors whereby maintenance requirements only need to focus on proper lubrication of the motor bearings. Thus no mechanical skills are required.

Latest technology development made it possible to introduce power switching devices that are capable of switching at high frequencies thereby making it possible to control AC motors.

A basic AC control system (Figure 5) is based on;

- Rectifier
- DC bus
- AC Invertor
- AC motor

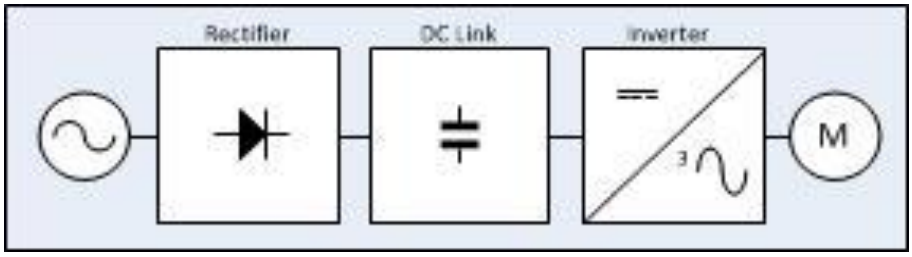

Figure 5. Basic AC Controller

The output of the AC invertor differs completely with the output of a Thyristor. Output of the AC invertor is based on Pulse Width Modulation (PWM) and the switching frequencies are normally from 4 kHz to 5 kHz (Figure 6). Simulated output frequencies can therefore be controlled, hence the term *Variable Speed Drives (VSD) /Variable Frequency Drive (VFD).*

This is substantially higher compared with the nominal 50Hz switching frequency of Thyristors.

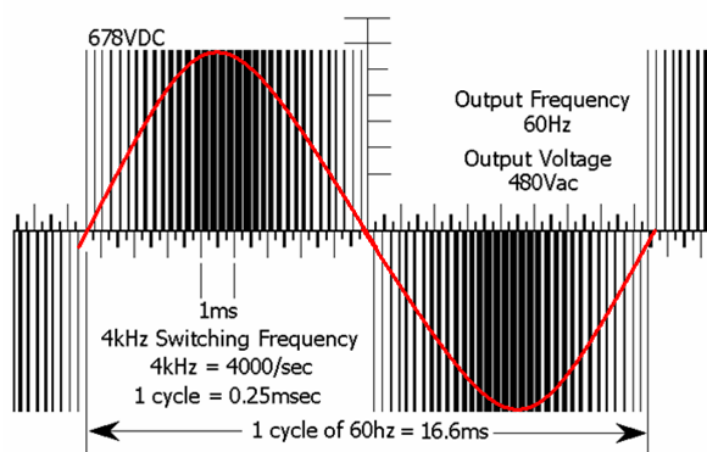

Figure 6. AC PWM Switching Frequency

The main advantage with this technology is that an AC motor can now be used thereby eliminating the on board machine step down transformer.

4. IEC GUIDELINES

Due to the rapid increase by industry in the use of VSD/VFD's, little work was conducted initially to identify possible disadvantages of VSD/VFD technology, and thus these issues only become apparent after being used in multi format applications.

Initial equipment failures led to international investigation into detail VSD/VFD applications and problems associated with the technology.

Equipment affected by this technology includes the following;

- Power Supply
- Transformers
- Cables
- Terminations

- VSD/VFD units
- Motors

IEC guidelines to engineers into the correct use of VSD/VFD's were published to ensure correct electrical designs are implemented. IEC TS 60034-25:2007 "Rotating Electrical Machines Part 25 Guidance for the performance of a.c. motors specifically designed for convertor supply" (Same as SANS 60034-25)

Of concern is that the ATEX Directive also issued guidelines in the correct use of this technology in hazardous locations due to the risks involved. Application of the ATEX Directive to Power Drive Systems: Variable Speed Drives and Motors. (Figure 7 clause 5.2.1.1)

5.2.1.1 Risk management of sparks

The motor and converter manufacturers will ensure that bearing currents are limited and sparks are prevented using techniques including:

- Suitable stator insulation materials and techniques (8)
- Reduction of voltage transients
  - Electrical filters
- Prevention of excessive bearing currents (9)
  - Insulated bearings or bearing housings, usually at the Non Drive-end
  - Reduced or optimised switching frequency
  - Electrical filters

Typical measures that may be recommended by the motor manufacturer include those shown in IEC 60034-17:2002, GAMBICA/REMA Guides No 1 and 2 and IEC 60034-25:2004

Figure 7. ATEX Directive Clause

Why is there concern about this technology?

Research has indicated that

- There are unintended currents flowing in equipment
- Energy large enough to cause "spark ignition" of gases in a hazardous location is present.

As a result, the guidelines in general therefore focussed on AC motors. AC motors in the surface industry are normally located within the hazardous locations.

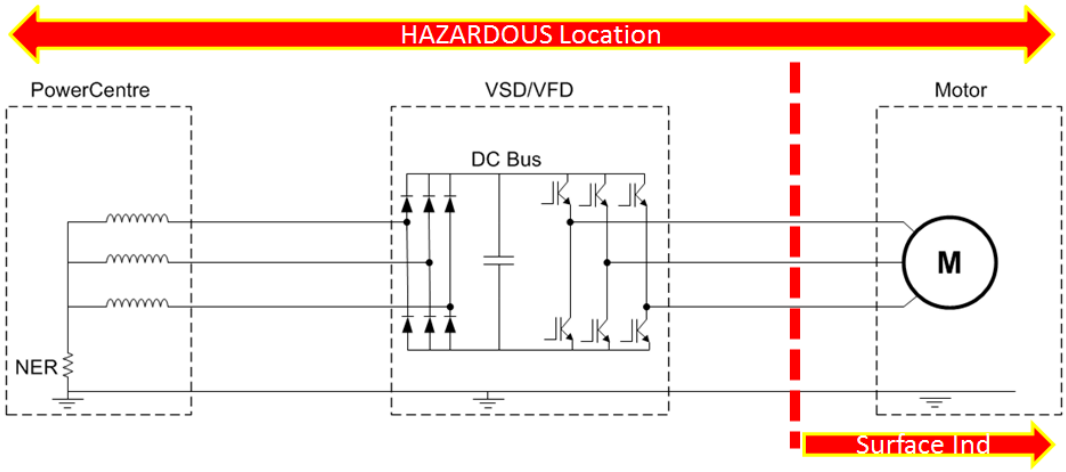

Figure 8. Difference in Hazardous Location for Coal Mines vs Surface Industry

In figure 8, the difference between Coal Mines and the Surface Industry is quite substantial. For Coal mines, the hazardous location includes;

- The Power Supply
- Power Centre
- VSD/VFD
- Motor

The Surface Industry is only focussing on the cable to the motor and the actual motor installation. Mitigation for the surface industry is therefore not practical for the coal mining industry.

DC bus voltages are substantially higher than the motor line voltage. The switching devices output peak to peak voltages will generate peak voltages to the motor that are substantially higher than the original intended designs. Figure 9 indicated worst case scenario and this is also the reason why the capacitance coupling induced voltages are higher than line to earth voltages experienced on Neutral Earth Resistor systems.

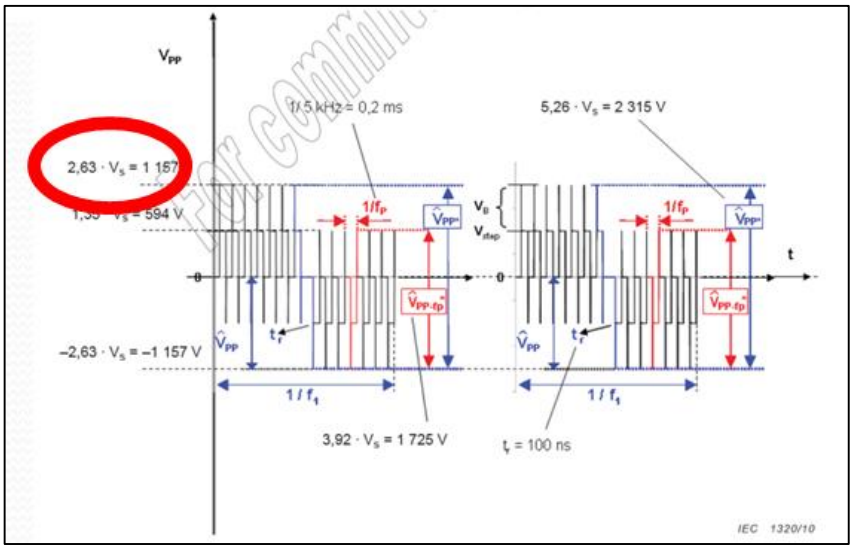

Figure 9. Worst Case Scenario Peak Motor Terminal Voltages Example

For a coal mine operating on 950VAC, this translates to 2 498.5V peak. Insulation on the system will be severely stressed.

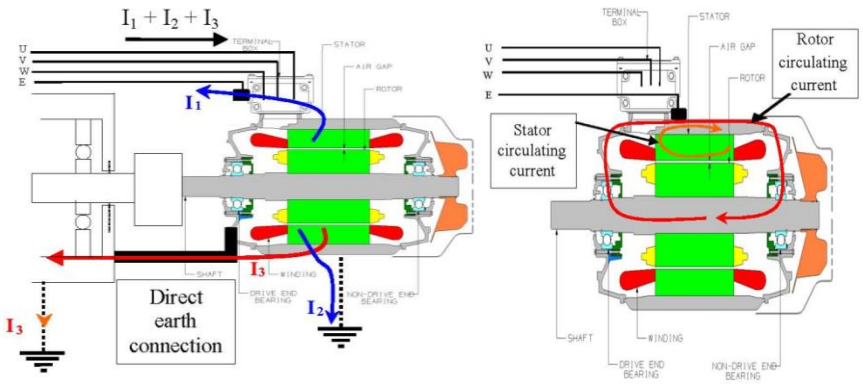

Figure 10. Motor Coupling Currents

Motors have different coupling current as a result of VSD/VFD switching supplies and the main focus for the surface industry is based on proper motor designs.

5. NEW VSD STANDARD

Both IEC and the ATEX Directive are only guideline standards and for South Africa, a standard that is regulated is required. A SANS TC 65 workgroup was formed to generate a standard for South Africa.

> *Assessing, Testing and Certification of Power Drive Systems (PDS) in Explosive Environments*

Recommendation based on SANS 60034 as well as the ATEX directive are being referenced within the new standard to ensure the risks associated with the use of VSD/VFD's are regulated.

However, as stated, the recommendations applicable to the surface industry cannot mitigate the risks associated with VSD/VFD technology used in hazardous locations for coal mines and requires a complete different approach.

As a result of the PWM frequencies involved, capacitance coupling to any other equipment other than the motor is not feasible and must be prevented at all cost.

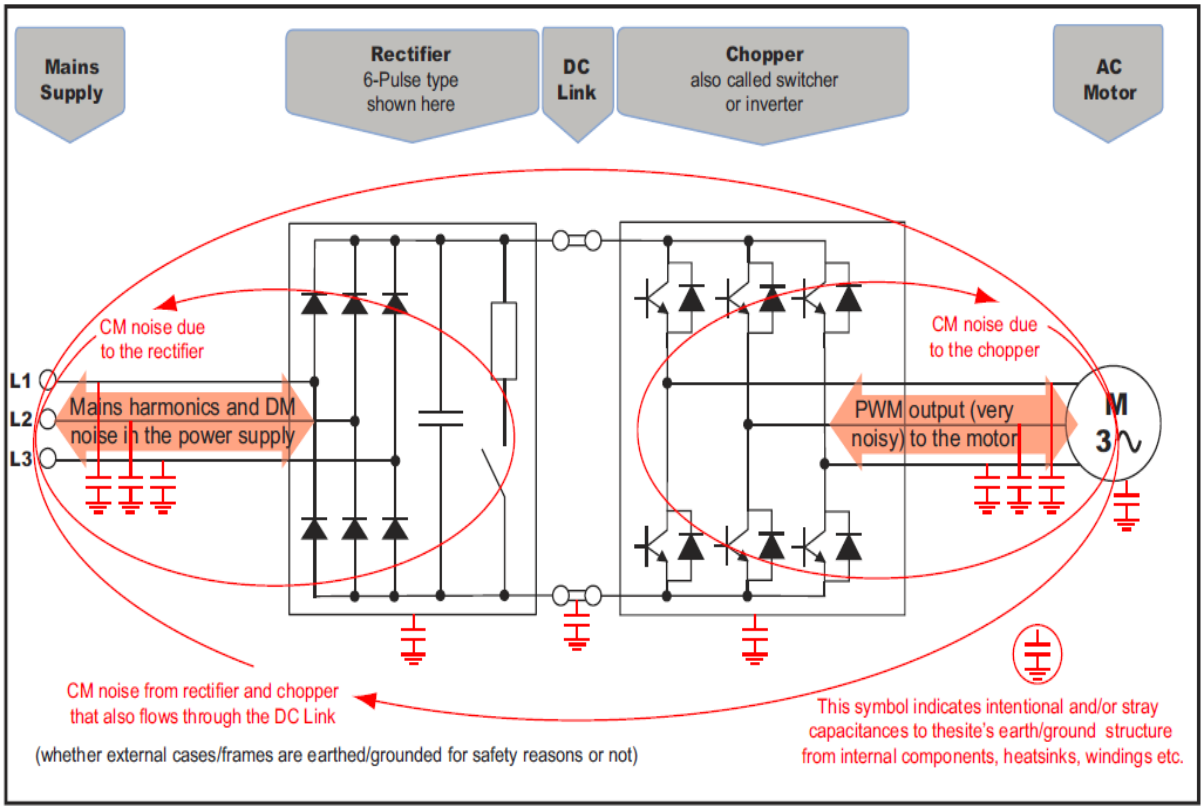

Figure 11. Typical Continuous Miner Capacitance Coupling Current Paths

Typical currents as a result of capacitance coupling (Figure 11) need to be avoided. For coal mines, the VSD/VFD is also located within the hazardous location and hence the VSD/VFD design must include means to eliminate any switching frequency having an affect outside the VSD/VFD unit.

As a result of the high frequency switching current that are coupled to earth, earth fault protection devices caused “nuisance” tripping. (Or so people thought) Filter system that filtered all earth fault frequencies above 50Hz were installed by protection relay manufacturers without really understanding the problem.

No design criteria for this situation exist and manufacturers of protection devices did not conduct proper investigations into the cause of the “nuisance” tripping. Needless to say that no risk assessment was done. (None available from the manufacturers)

At present, VSD/VFD units are operating in hazardous locations that pose a significant “spark ignition” risk as well as dangerous touch potentials being present between mining machines.

For coal mines, the only practical option is to include proper filtering systems before and after the VSD/VFD unit.

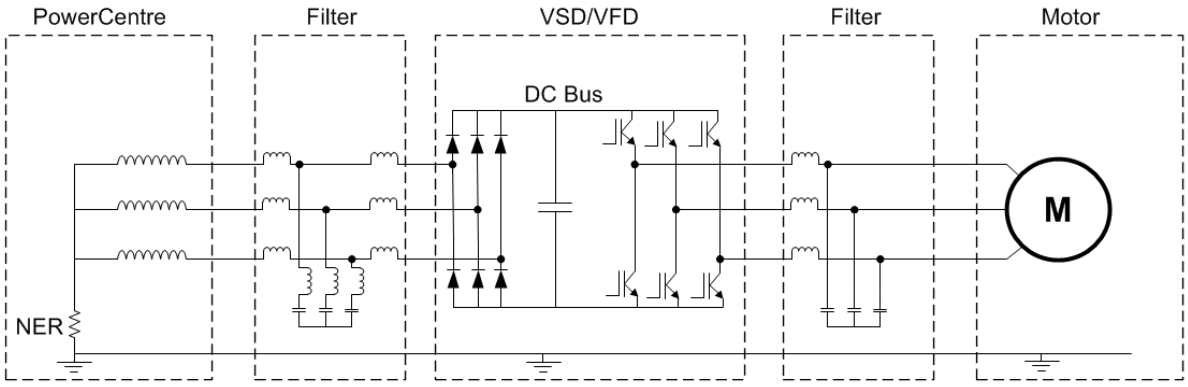

Figure 12. Typical VSD/VFD Filter System

The filter system recommended as indicated in figure 12 has no coupling to earth and keeps the filtered currents between the power conductors.

6. IMPACT OF THE NEW VSD STANDARD

The only recommendation for the coal mining industry is to use proper designed filters for the VSD/VFD units.

However, with the recommendation comes a problem. In order to filter the high frequencies, inductors/reactors must not saturate and to overcome this, the inductors/reactors becomes extremly large.

Secondly, the di/dt determines the torque capability of the motor. (Start currents) Any additional conductors add impedance and hence limit the torque capability of the motor. Therefore, the inductors/reactors must be selected to address both problems and the result is a very large filter system.

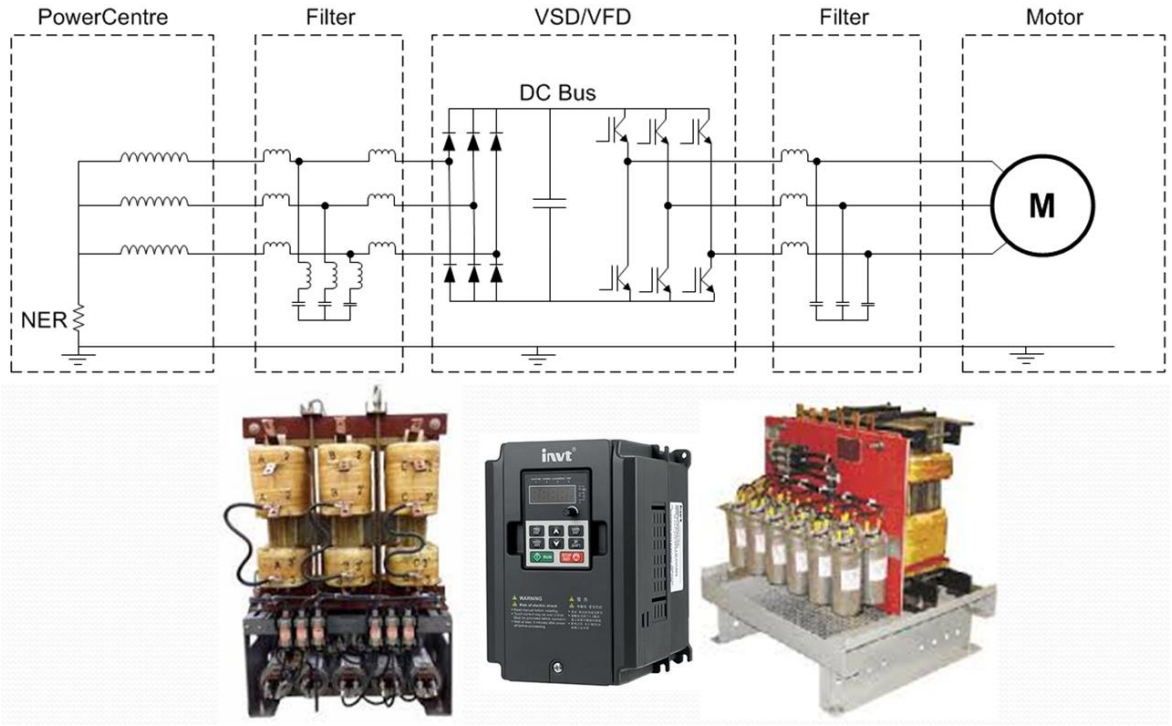

Figure 13. Recommended VSD/VFD Filter System

As indicated in figure 13, the recommended filter system is extremely large and must still be housed in an EX d enclosure (Flameproof).

The challenge will be to find a suitable location on an already compact machine to install the filter system.

In order to mitigate the existing risk, machines that have VSD/VFD units installed must be retrofitted with proper designed filter systems.

These systems will be required to be certified by an Approved Test Laboratory (ATL) and must pose no risk when used in hazardous locations on coal mines.

7. CONCLUSION

By Default, original DC technology made it possible to safely control machines in Hazardous Locations. The major drawback of this technology is that it is maintenance intensive.

Replacement VSD/VFD technology if used correctly can be used safely in Hazardous Locations if;

- Spark ignition and
- Touch potentials are eliminated through correct application of filter system designs.

The challenge to the coal mining industry is to safely package the complete VSD/VFD, filter system and EX d enclosure on a machine. In order to achieve this, further development is required and manufacturers are urged to get involve with producing a practical solution for the coal mining industry.

Protection devices must function as intended ➔"To eliminate Risks to personnel and equipoment". Manufacturers are required by legislation to conduct "design" risk assessments to ensure risks are addressed safely within their designs.

VSD/VFD total solution

- will be more expensive as a result of complying with the new requirements.
- must be "fit for purpose" and must operate reliaibly and safely.

Manufacturers are therefore invited to join the new SANS working group in order to produce a practical and workable standard for South Africa.

Please contact the SANS working Group convenor at

Jabulani Nhlapo : jabulani.nhlapo@sabs.co.za

REFERENCES

1 SANS TC 65 *VSD work group*
2 IEC TS 60034-25:2007 *"Rotating Electrical Machines Part 25 Guidance for the performance of a.c. motors specifically designed for convertor supply" (Same as SANS 60034-25)*
3 Application of the ATEX Directive to Power Drive Systems: *Variable Speed Drives and Motors*
4 SANS *Assessing, Testing and Certification of Power Drive Systems (PDS) in Explosive Environments*
5 SANS 60079-Series
6 MH&SA

HENK ZWART

Henk gained a BSc in Light and Heavy Engineering from Potchefstroom University, followed by a GCC (Electrical) and in 2006, an MPD. He has over 25 years' experience in the electrical engineering field holding positions such as principle electrical engineer at Anglo American Coal Division for whom he worked for 22 years. He now works as a private electrical engineering consultant based in Emhalaleni (Witbank), Mpumalanga, where he provides a comprehensive range of services to the mining industry. He is a registered Pr. Eng. and Pr. Cert. Eng., as well as a council member of SAFA and SACEA, and has participated in a number of working groups drafting and updating national standards.

Henk Zwart
Electrical Engineering Consultant
Emhalaleni, Mpumalanga
Cell: +(27)82 527 0585
Email: henk.zwart@vodamail.co.za