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FIELD TESTING AND RELIABILITY ASSESSMENT OF VIDEO BASED FIRE DETECTION IN COAL MINING AND COAL HANDLING ENVIRONMENTS

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Abstract: Previous laboratory test results and numerical modelling showed that Video Based Fire Detection (VBFD) offers a means of providing earlier fire detection compared with traditional carbon monoxide (CO) detectors in typical Australian underground mines. Additionally, from a reliability viewpoint compared with VBFD, CO detectors are subject to sensor drift and insensitivity as a result of contamination of the CO sensor device as reported by the National Institute of Occupational Safety and Health (NIOSH). The reliability of VBFD in an underground mining environment was unknown until field-testing as the final part of this research program was carried out.

An advantage of VBFD over traditional alternatives is that the camera lens does not have to be exposed directly to the products of combustion of a fire and can view the fire effects from a distance. Given the correct operational conditions to detect early smoke (or flame), including appropriate light and a suitable viewing arrangement, VBFD provides the required early detection needed to detect early smoke production from underground mine fixed plant fires. The question of whether the harsh environment that the VBFD cameras are exposed to, such as from coal dust and diesel fuel particulates has the potential to obscure the camera vision leading to a loss of VBFD detection capability and even unwanted alarm activation, was successfully answered. The results of the Arnot Power Station investigation indicated that if proper commissioning is carried out and effective maintenance is employed, a reliable means of early smoke (and flame) detection in underground mines is possible using VBFD.

This chapter concludes a three part research project in investigating and developing VBFD to improve fire life safety and asset loss control in underground mines. Overall, it found that VBFD is a more effective and more robust approach to providing timely fire detection and warning than traditional CO detectors in typical Australian underground mines.

INTRODUCTION

The effectiveness of Video Based Fire Detection (VBFD) to detect early smouldering fire has been previously experimentally compared with traditional Carbon Monoxide (CO) sensing under simulated mine conditions in a laboratory at the Safety in Mines Testing And Research Station (SIMTARS). It was found that VBFD reacted to very low level pyrolysis fires simulating overheated conveyor belt bearing housings, however CO sensing in most of the experiments recorded very minimal (or nil) levels of CO in sensor locations surrounding the fire source. Subsequent numerical modelling estimated similar results to the experiments, so the Computational Fluid Dynamics (CFD) was considered to validate the SIMTARS experiments. (Mendham *et al.,* 2014*a*, 2014*b*).

The aim of the VBFD field study was to review and utilise the results of installation commissioning data and operational testing of a VBFD system in an operational underground mine environment. The purpose was to inform the underground mining industry of limitations that may exist in terms of the VBFD reliability in service, such as potential maintenance issues. It also sought to identify and address any possible inconsistent VBFD operation with respect to false positive alarm activation. Unfortunately,

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one main factor influenced not being able to install a VBFD system in a working underground coalmine to facilitate this testing. During the period of the subject study into VBFD as a means of improving fire life safety and asset loss control in underground mining, the Australian resources industry moved from being in a position to readily facilitate and support minor external unfunded research projects within its underground mine assets to the current position where it is no longer willing to assist. As a result of the lack of a trial VBFD system in an underground mine, the subject field study opportunistically considered the reliability and performance of VBFD in a very similar and related environment, however this facility was not an underground mine.

The manufacturer of the VBFD equipment advised that a coal fired power station in South Africa had recently been fitted with an extensive VBFD system, including coverage in coal handling and storage areas (Mottley 2015). This location was considered an alternative to field-testing a VBFD system in an underground mine, as the coal handling systems are very similar and the level of airborne pollutants are also likely to be comparable.

Arnot Power Station is an asset of Eskom Holdings Limited located approximately 50 km east of Middelburg in Mpumalanga, in South Africa. Eskom advise that it was originally constructed in 1965 through 1966 and commenced operation in 1968. As a result of surplus power available at the time, Arnot was mothballed in 1992, but was recommissioned in 1998 due to growing power demands. Technical details (Eskom 2015) are as follows:

- Six (6) x 350MW generator units
- Installed capacity of 2,100 MW
- 2001 capacity of 1,980 MW
- Design efficiency at rated turbine Maximum Continuous Rating (MCR) (%): 35.60%
- Ramp rate of 34.48% per hour
- Average availability over last 3 years of 92.07%
- Average production over last 3 years of 9,675 GWh

Arnot mine is situated some 43 km from Middelburg in South Africa's Mpumalanga province and feeds Arnot Power Station. This mine extracts coal using both underground and opencast operations, employs 1100 employees (with an additional 300 contract employees deployed in the opencast operation) with a run of mine of 1.44 Mt of thermal coal. Arnot uses mechanised mining methods and continuous mining processes. The mine is contracted to supply Eskom's Arnot Power Station with coal on a "cost-plus" agreement in which there is a return on investment and a management fee. The mine has a coal reserve base of 54.2 Mt and a resource of 250.3 Mt. Coal is fed to Arnot Power Station by overland conveyor (Exxaro 2015).

The ongoing refurbishment works at Arnot incorporated a comprehensive fire detection system involving 360 commissioned VBFD cameras reporting to one control room using a Spyderguard ™ system. C3SS Ltd. (C3SS) of Johannesburg, RSA, installed and commissioned the VBFD system between 2014 and 2015. It was noted during inspection that many areas in coal-fired power stations involving the use of fixed plant have similar functions and fire risks to underground coalmines. Reviewing the power station fire risks and its VBFD system performance in a location that contained many of the fire risks and types of fixed plant found in an underground mine was considered useful in generally assessing the potential reliability of VBFD in mining applications.

The relevance of using a power station as an alternative to an underground mine for the assessment of VBFD reliability and performance is that Arnot Power Station currently has one of the world's largest and newest industrial VBFD installations throughout all areas of this large facility, including within its extensive coal handling and bunkering areas. Environmentally this scenario is very similar to a typical Australian underground coalmine and was considered an appropriate means of assessing VBFD reliability and performance at a test location. The assessment showed that 'dirty' camera housing lenses, occurring as a result of coal dust deposits and similar pollutants potentially obscuring the fire detection scene, have little effect on detection capability up to a threshold alarm point that warns the operators of an impending reduction in detection performance unless the view is reinstated. Interestingly, the method of cleaning the lenses at Arnot was quite non-technical: a 'feather duster' is located at each VBFD detector and is applied on both infrequent occasions by operators in anticipation of an automatic threshold alert from the VBFD management system and on a scheduled basis. Whilst this may not be directly comparable for underground mines, it highlights the reliability and robustness of VBFD.

AIMS

The aim of the field-testing was to demonstrate whether VBFD can reliably and effectively be utilised in an underground coal-mining environment based on its operational performance in a similarly onerous environment, being a coal fired power station. The specific field-testing aim was to observe and report on two reliability related VBFD areas of interest also applicable to mining. These were:

1. VBFD Failure
2. VBFD False Response

Generally, VBFD failure in service could occur as a result of one of a number of possible failure modes. The following is a non-exhaustive list of such potential failure modes:

1. Failure to view potential fire risk due to contamination/obscuration of the VBFD lens or the external camera housing lens with particulate matter, such as coal or stone dust;
2. Failure of communications between the VBFD CCTV cameras and the control room;
3. Failure of the VBFD CCTV camera including power supply.

In the context of VBFD alarm inconsistency, which may be caused by false positive alarm stimuli, the following list is non-exhaustive and summarises inappropriate response modes:

1. Incorrect recognition of smoke-like phenomenon such as dust or steam as smoke;
2. Incorrect recognition of reflected light or direct light on the VBFD interpreted as smoke;
3. Discolouration of sections of conveyor belts in motion creating smoke-like appearance;
4. Inadequate or inappropriate illumination of the smoke plume;
5. Motor vehicle lights or cap lights shining on VBFD lenses or viewed sections of airborne particles (as per Item 2);
6. Motor vehicle and portable plant exhaust fumes;
7. Reflections from Personal Protective Equipment (PPE) such as reflective stripes and
8. Ingress of water into VBFD components.

METHOD

In order to focus the analysis of VBFD reliability and its performance at Arnot Power Station over a succinct investigation period, areas of the power station analogous to underground mines were identified for subsequent review. In the case of a typical coal-fired power station these areas were those used for the handling and storage of coal. The method utilised to identify these areas was to carry out a firsthand supervised inspection of the facility involving the recording of information about suitable locations where VBFD existed that were considered similar to underground mine scenarios. Additionally, photographs and diagrams were assessed on site to obtain a more thorough understanding of the power station layout and functioning and how VBFD is applied in each situation. After the identification of locations that were considered analogous to typical Australian underground coalmines, commissioning test results and progressive maintenance records for each applicable VBFD camera were reviewed. Alarm activity logs were then accessed to identify whether or not the alarm activations are likely to have occurred as a result of actual fires or as false positive activations.

In summary, the method utilised to collect VBFD reliability and performance data at Arnot Power Station included:

Method 1: Identification of locations analogous to underground coal mines and factors associated with the environment;
Method 2: Review of commissioning and maintenance data of VBFD in the identified locations to assess VBFD reliability;
Method 3: Reliability review of alarm activation logs to assess 'Real versus False Positive' activations, the identification of possible causes.

The methodology involved the review of actual VBFD images / recordings, which were analysed to assess the performance of commissioning tests and subsequent VBFD activations.

RESULTS

VBFD locations analogous to underground mines included:

1. Coal Staithe Transfer Area; (Refer 1)
2. Coal Staithe conveyors; (Refer 2)
3. Inclined conveyors to coal bunkers; (Refer 3)
4. Coal staithe drive pulleys; (Refer 4)
5. Coal bunkers; (Refer 5)
6. Coal bunker walkways; (Refer 6)
7. Coal bunker conveyor offload areas; and
8. Coal bunker tail pulleys.

Clearly, numerous locations within Arnot power station closely resemble underground coalmines, so the relevance of VBFD assessment in these locations was found to be pertinent.

Commissioning and maintenance

The commissioning of the VBFD system at Arnot Power Station was quite extensive, as it involved 360 cameras and was in accordance with the requirements of Fike Ltd, the equipment manufacturer (Privalov and Lynch 2012), the applicable standards of South Africa (SANS 10139, 2012) and international standards (NFPA 72, 2015). Except for the South African national standard, these prescriptive requirements also apply to Australian underground mines from both a regulatory and insurer perspective. One significant point of interest is that the commissioning tests listed in these standards are less onerous than the laboratory tests previously carried out at SIMTARS by the first author. The VBFD tests at SIMTARS required much smaller smoke plumes to be accurately detected than those stipulated in the standards. The VBFD installation and commissioning standards require commercially available '90 second Smoke Emitter Candles' to be used as the source of smoke such that the VBFD must be able to detect the simulated smoke generated by the candle. The VBFD does not necessarily have to operate within the 90-second smoke emitter discharge period, as the residual smoke subsequent to the extinguishment of the candle may be required to spread from its emitter source to within the programmed field of view of the VBFD camera.

The installers and commissioners of the VBFD system (Grange 2015) emphasised the requirement to commission it in accordance with the manufacturers' specifications and with the appropriate standard to ensure that the installation will operate as intended without unexpected outages.

The required commissioning tests were:

1. VBFD field of view is clear of all obstructions not usually in view;
2. The camera image quality is adjusted to optimum level;
3. Confirm no physical damage to the VBFD camera or wiring;
4. Field Of View (FOV) is set up top include roof (ceiling), target image and floor;

5. Content Fault (for smoke detection only);
6. Network Fault (if Applicable);
7. Power Loss; and
8. Analytics Functioning.

Figure 1: VBFD CCTV in Coal Staithe Transfer Area

Figure 4: Coal Staithe Conveyor Belt Drive Pulley

Figure 2: Coal Staithe Conveyors

Figure 5: Coal Bunker

Figure 3: Inclined Conveyor from Coal Bunker

Figure 6: Coal Bunker Walkway

VBFD images may be divided into various zones for a number of purposes, such as facilitating identification of smoke spread in a space, or activation of suppression systems at specific fire zones. Zones of a VBFD screen view can be programmed to 'do nothing', that is, be excluded from the VBFD surveillance. VBFD exclusion zones are sections of the image that can be isolated from the smoke (or flame) detection process so that if smoke like phenomenon is expected to occur in these excluded areas, it does not initiate an alarm.

Advice was received in relation to the field of view of the VBFD cameras. The installers (Grange, 2015) experience was that the VBFD cameras more effectively detect smoke when the field of view includes the ceiling and floor as well as the potential target fire source. Grange further explained that it is imperative that an appropriate amount of time be taken to fine-tune the VBFD 'exclusion zones'.

VBFD Reliability

Periodically, where intense floor and equipment cleaning is carried out involving high pressure water cleaners producing considerable dust plumes that resemble smoke plumes and water vapour movement involving unstable changes to ambient light levels through the introduction of specialised relocatable work lighting – VBFD alarm activations had occurred as shown inTable 1.

Table 1: Summary of VBFD issues

Category of VBFD Issue	Frequency Per Year	Typical Cause	Typical Resolution
VBFD False Response	Five (5) per 360 VBFD units	Plant cleaning activities. (Typically: high-pressure water cleaning).	Isolate VBFD until maintenance activities completed. Operators instructed to advise prior to carrying out next high-pressure water cleaning activity.
VBFD Failure	Two (2) per 360 VBFD units	Obstacle placed in FOV. (Typically: portable crane or gantry in FOV).	Isolate VBFD until obstacle removed.

The contractor (Grange, 2015) explained that VBFD has limitations in terms of discriminating the 'signature' of smoke from phenomenon that appears smoke-like. These limitations need to be taken into account by operators and those carrying out activities that are similar in nature to creating smoke. The advantage of VBFD over other forms of smoke (or flame) detection is that VBFD provides the opportunity for manual intervention by the control room through the ability to actually view the potential fire on-screen. Of course, in the absence of manual intervention (e.g. unstaffed control room) the VBFD system may be configured to continue the fire recognition process automatically to generate a fire evacuation cue or initiate automatic fire suppression.

The developing capability of VBFD to accurately detect and discriminate fire phenomenon from other smoke-like phenomenon is managed under the VBFD developer's continuous improvement processes. Additionally, maintenance activities need to be carried out to ensure the VBFD system can operate effectively without being impacted by reduced field of view through dust build-up on the lens and reduced illumination.

If not managed, dust contamination of the VBFD camera lenses will cause them to fail to detect a source of smoke, however this is countered by the VBFD analytics generating user programmable warning alarms to the controllers advising that lens obscuration is nearing a threshold and maintenance intervention (cleaning) of the VBFD camera lens or the camera-housing lens is required. All VBFD camera lenses are 'dry' cleaned at Arnot Power Station using a domestic feather duster applied every two (2) weeks. An image showing the level of surface dust accumulation on VBFD cameras in typically 'dirty' locations is provided in Figure 7 whilst the typical view from a camera with an obscured lens achieving 55.79% visibility, is shown in Figure 8.

Figure 7: Typical Dust Accumulation on VBFD CCTV Camera

Figure 8: Obscured view from VBFD camera with 55.79% (Dirty Lens) visibility

The VBFD installation firm (C3SS) advised (Grange, 2015) during the site interview that there had been no VBFD failures specific to the 360 installed CCTV cameras, however some minor outages had been encountered due to work by others causing loss of communications through cabling disturbance, such as disconnections of fibre optical cables without proper notice. These instances were system failures rather than failures specifically associated with the VBFD installation.

DISCUSSION AND CONCLUSIONS

The performance and reliability of VBFD at a coal-fired power station in South Africa was reviewed, because this installation has many similarities in its operations to typical underground coalmines, so parallels could be drawn from this in the absence of an available underground mine VBFD system. These similarities are clearly evident in coal conveyor belt systems, transfer points and coal bunkering facilities.

At Arnot Power Station these areas have VBFD implemented throughout, as might similarly be the case in an underground coalmine. Arnot is the largest VBFD installation worldwide with approximately 360 VBFD cameras installed, as reported by Fike, the VBFD manufacturer (Mottley, 2015). Arnot power station was a source of considerable VBFD reliability data representing knowledge that could be transferred to VBFD installations used in underground mining in Australia.

This investigation has shown that VBFD systems can effectively be incorporated in locations that are affected by airborne pollutants including coal dust, water mist and mist hydrocarbons. It was identified that it is essential that the VBFD systems be properly installed and commissioned in accordance with regulatory requirements and in particular, manufacturers specifications. Commissioning adjustment will involve the careful observation and subsequent blanking out of potential sources of false activation of the VBFD.

VBFD systems require a level of maintenance specific to their environment. In the power station they required dry cleaning of the lenses on a regular basis and in underground mines it is likely they will require a similar level of attention. Future research in relation to VBFD reliability might specifically identify ways of ensuring camera and housing lenses require very little cleaning and maintenance and this could be as a result of self cleaning lenses that incorporate external air supplies that prevent dust deposits on the lens surface.

The results of the Arnot Power Station investigation indicated that if proper commissioning is carried out and effective maintenance is employed, a reliable means of early smoke (and flame) detection in underground mines is possible using VBFD.

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