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Technology convergence for sustainable underground mine ventilation system control

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ABSTRACT: Underground mining has yet to see an industry wide solution for control of their ventilation systems due to the complexity and sensitivity of the underground environment. Complexity arises from multi-level, multi-zone operations and sensitivity is associated with the impact that changes in equipment status and output have on air flows and quality throughout the mine. Our approach to solving this challenge incorporates system modeling and industrial control systems in a unified architecture. Although this approach can be applied to other processes and industries, this paper will cover the theoretical and practical aspects of an integrated model-control system (MCS) as it applies to underground mining ventilation.

1 Introduction

Mine ventilation provides life sustaining air to personnel working in extreme operating environments often hitting temperatures of 40°C at depths more than 3,000m. Delivery of this air to locations in the mine where it is required while minimizing wasted air and recirculation is the balancing act faced by those responsible for design, operation and maintenance of these systems.

This balancing act is where the interest for pursuing our solution comes into play. Effectively operating ventilation systems based on optimized design ensures energy consumption utilized by ventilation related equipment—often representing 35% to 45% of a mine electrical energy load (Hardcastle, 2007)—will be minimized while production requirements are met throughout shifts and throughout the life of the mine. The best decisions on hardware components such as automated regulators or variable speed drives can now be considered for the mine as it evolves.

The difficulty of this optimized operation lies in the mine operator's ability to effectively manage several software and hardware systems while maintaining current production demands. Current state of affairs can be compared to using one software program on one PC for incoming email, another for outgoing and a third for schedules. This was acceptable before MS Windows 3.1 but technology has reached a point where the entire process of design, control and maintenance can be performed in a streamlined fashion.

Previous attempts at ventilation-on-demand solutions included the best technologies available at the time of implementation. These included PLC-based (Programmable Logic Controllers) timers operating at the fan level, HMI-based (Human Machine Interfaces) scheduling scripts and distributed tagging systems tied to local controllers. These approaches dealt with only one-dimension of ventilation control and lacked the ability to manage the ventilation system as a whole. Moreover, they lacked the ability to dynamically change with the ever changing mining plant. Our MCS (Model-Control System) incorporates all aspects of ventilation control to give operators a complete solution for their long term ventilation needs.

The key components of this MCS include ventilation modeling software, control system hardware and software and communication infrastructure. This has resulted in a robust and reliable architecture capable of maintain safe underground operating conditions while optimizing energy consumption.

The system components and model-control system software interface will be discussed in detail in this paper in relation to their roles, data flows and information requirements.

2 System Components

This section will describe the main components of the MCS including field devices, communication

Infrastructure, server hardware, control system software and modeling software as shown in

Figure 1. Each section will describe the component, the role it plays within the system and the enhanced use of these components within the MCS architecture.

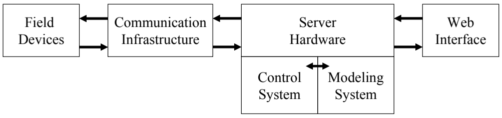

Figure 1: Block diagram of MCS components

2.1 Field Devices

The connection point between the underground environment and the MCS architecture lie in the field devices. These field devices measure operating parameters as well as air flow and quality for use as feedback for the model and control system. Advanced uses of field devices within the MCS architecture include a local control layer that can provide auto-calibration based on historical data processing, auto-configuration of automation logic based on PLC I/O (input/output) configuration, position detection based on historical data comparison with model results and more importantly redundant safety control logic in response to communication infrastructure downtime. The extent of instrumentation required for effective ventilation control must be assessed based on the mine's ventilation model. Key points within this model will then be instrumented along with heavy production or development areas. The location of the key points will evolve over the life of mine in conjunction with changing activities. The system can then be used to plan the long term instrumentation and automation needs of the underground mine.

2.2 Communication Infrastructure

The communication infrastructure allows data to be transmitted from the field devices to the server hardware. Underground communication systems range from traditional leaky feeder systems to modern fiber optic or 802.11 wireless networks. Several mines have hybrid systems that leverage legacy and cutting edge technologies and this was taken into account in the design of the communication layer within the control system. The MCS is designed to utilize OPC Standards for communicating on a wide variety of systems.

2.3 Server Hardware

Stability and reliability of the server hardware will enable the MCS to operate on a continuous basis with minimum downtime. This section will describe the generic requirements for the server due to the speed at which new server technologies come to market.

The first requirement is the server's ability to run an ASP.NET web server, the .NET Framework and SQL databases. This requirement drives the need for a Windows Server operating system or professional version of the Windows operating system. A mention of alternative platforms will be made in the 'Future Work' section.

The recommended architecture for a full implementation of the MCS for ventilation control is to create set of servers where one server hosts the web server, one server hosts the databases and one hosts the OPC communication layer and data processing services. This minimizes the impact potential hardware or software failures will have on the performance of the MCS.

Battery back-up systems for maintained operation during power outage and clean shut down and start-up during extended power failures is required. Back-up technologies are specified based on the duration the servers must operate and the power requirements of those servers. Minimum specification is the ability for the software to shut down in a controlled manner. In the case of server hardware failures the MCS reverts to a fail-safe mode defined by the mine operators using the field device level control.

2.4 Control System

The control system chosen for the MCS architecture is NRG-1. NRG-1 is a web-based control system capable of handling 3 control streams namely event-based, schedule-based and real-time. These three control streams provide operators with universal flexibility for managing their systems to keep pace with evolving requirements.

NRG-1's role within the MCS architecture is to process the inputs from the field identify actions to take in conjunction with schedule and operator controls, compare control commands with model prediction results and execute control commands accordingly.

Processing inputs from field devices for the MCS architecture extends beyond traditional data logging techniques. The systems utilizes the input from the devices to decide whether control commands have been executed as expected, whether an event is being triggered and whether a device is behaving as the model predicts it should. This processing takes place inside a Windows service and utilizes an SQL database for temporary and permanent storage in case of communication failures.

NRG-1's biggest challenge is to manage the execution of control commands that are generated asynchronously by any of the three control streams. This is accomplished through the development of a sophisticated resolution algorithm.

Sending commands out to the field devices allows NRG-1 to control the MCS architecture device. NRG-1 also monitors the device status to determine whether the command was successful. This feedback can also be processed through the model in order to verify or recalibrate the model.

2.5 Ventilation Modeling System

The control system chosen for the MCS is Windows service version of VnetPC (insert web reference). This version has also been updated with an SQL database and enhanced user interface. VnetPC provides the MCS with results regarding queued control changes. The control changes are executed within the model by changing fan and regulator parameters and providing the system with predicted air flows. Traditional use of the ventilation modeling software has been restricted to the design and planning phases of mines where as this added flexibility of real-time model updates and feedback allow it to run in conjunction with production activities.

Enhanced results of this inline modeling give the MCS a unique ability to verify the control commands being executed ensuring the mine ventilation will remain in a safe operating state.

Initial configuration of the model takes place through a Windows application interface. Updates are provided to the system through CAD drawings on an on-going basis which minimizes the work required to maintain a valid model. Model predictions and baseline measurements from the field must be within a 10% tolerance of each other. Errors larger than 10% between actual and predicted values will force the system into the field controlled fail-safe state.

3 Model-Control System Interaction

This section describes details of the interface between the control system and the model. VnetPC and NRG-1 communicate through a common database and handshaking system. VnetPC passes its model results to the common database once NRG-1 has identified the required configuration change.

VnetPC provides a list of airflows for the segments identified in the model based on pre-defined operating parameters. These operating parameters take into account the fan curve efficiencies and losses throughout the mine due to frictional losses. Changing air density with deep mines can be accounted for by simulating losses at certain depths within the mine. Accounting for auto-compression becomes important as the depth of the mine reaches down past 187m-1250 (4000 to 6000 feet) (Bovin, 1983).

Once the air flows have been calculated, NRG-1 reads the tables and compares the segments to the available field devices. This comparison looks at two historical baseline datasets. The first dataset is generated by the model for various model scenarios which provide air flows for the segment across a broad range of system states. The second dataset is a calibrated field sample for a period of 30 days for air flow. At this point in time the only parameter being processed through the model interaction is air flow.

Proprietary signal processing techniques are then used to compare the following combination of signals:

- **Baseline Model vs. Processed Model**
- **Baseline Field Device vs. Actual Field Device**
- **Processed Model vs. Actual Field Device**

The first comparison is used to determine if the state being requested by the model is within the expected range for that segment based on historical model data. For example, the baseline model results for a particular segment contain CFM reading ranging from 18.9m^3/s (40,000 CFM) to 28.3m^3/s (60,000 CFM). The range will be determined by the number of operating scenarios executed during configuration. The selection will be based on the % confidence level users expect for each segment. In this example, if the processed model result is calculated to be 16.5 m^3/s (35,000 CFM) the system will send notifications that the current configuration has not been identified in the model baseline dataset. This is an indication that too little iteration was used in creating the model baseline or the accuracy of the calibrated model is not adequate. Both conditions can be easily corrected.

Baseline field device comparison with actual field device data automatically detects drift and dispersion. This comparison leads operators to calibration related issues although it can also be used for location identification of the device. The baseline data for the field device for a period of 30 days is intended to cover 80% of the operating conditions expected for the next 5 years of the mining operation. If the actual field device is out of range of the expected results in terms of drift or dispersion then notifications are sent to operators. The other cause is that the instrument is no longer in the same location and has a new dataset profile that must be stored in the MCS. Again, this form of mistake proofing enables the long term use of the MCS with minimal downtime.

Once the previous two comparisons have passed, the processed model data comparison to the actual field device data can be made with confidence. The comparison allows users to determine if the control commands being tested in the model will create low air flow to activity ratios underground and if any short circuits are going to be created. Operators can then halt the execution of modes as a result of this feedback or proceed with the knowledge about the state and re-organize ventilation through design changes.

4 Conclusion

The MCS architecture is capable of effectively controlling underground mine ventilation systems through the advanced use of existing industry components as described above. This unique platform binds design and operations, forcing accountability for actions as they relate to ventilation. Maintaining regulated air qualities while minimizing energy consumption yields results that lead to a sustainable solution.

5 Future Work

- **Implementation of MCS at Vale INCO mining operation**
- **3-D graphical interface for visualization of ventilation segment sensitivity**
- **Integrated mine planning and scheduling capabilities with design and control tools**
- **Redundant hardware architectures with hot-swap capabilities**
- **Unix operating system compatibility**

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References

Bovin, A A, Kurlenya M V, Shemyakin E I 1983. Problems of extracting deposits of useful minerals at great depths, *The Journal of Mining Science*, 19(3):221-229

Hardcastle, Kocsis, and Lacroix, 2007. Strategic mine ventilation control: A source of potential energy savings, in *Proceedings of the CIM Conference 2007*

Microsoft® Research, 2008. *http://research.microsoft.com/mesh/* Self-Organizing Neighborhood Wireless Mesh Networks, January.