THREE GENERATIONS OF COAL LOADING CONTROL

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Abstract: A new control system for Anglo Coal's Rapid Loading Terminal was commissioned in 2003. This paper reviews the history of the control systems at the terminal, highlighting the radical changes in hardware, software and system architecture that have taken place since it was first opened in 1976.

Keywords: Routing; microprocessor control; rail traffic; programmable logic controllers; load dispatching.

1. INTRODUCTION

Situated near Witbank in Mpumulanga province of South Africa, Anglo Coal's Rapid Loading Terminal ("RLT") serves four of the company's mines in the area, loading up to one million tons of coal a month onto railway trains for onward transport. Most of this coal is destined for export through the Richards Bay Coal Terminal ("RBCT"), although selected inland customers also receive loads from RLT. At busy periods the terminal may be receiving coal from three or four mines while up to three trains are being loaded. The control system enables all of these operations to take place simultaneously, without the possibility of cross-contamination between batches, while also maintaining complete records of all coal movements for accounting purposes. With some minor variation, each generation of control system to be described below has performed all of these functions, although with notable improvements in sophistication and ergonomics over the time span of twenty-four years covered in this paper.

Opened in 1976, the RLT receives coal from the mines via overland conveyors, that from Kleinkopje Colliery being the first horizontally curved conveyor in the country. The coal is prepared at the mines to the required shipping specifications, then stockpiled at the RLT until required for loading. There are significant price differentials between the various grades of coal, so it is important that each of them is held separately and contamination is avoided. Production from each mine is also kept separate for accounting purposes, so the terminal has as many as thirty stockpiles at any one time. A network of conveyors, chutes and bins is used to transfer coal to the loadout stations when a train is ready for loading, which takes place at the rate of up to 8 000 tons per hour. A full train of 100 wagons is required to be loaded and despatched in less than four hours, in terms of the agreement with Spoornet, the South African railway operator. The terminal operates around the clock, 6 days per week.

The requirements for a control system for the RLT have remained unchanged over the years – speed, accuracy and reliability. Manual control and relay-based interlocking was adequate initially, when the terminal served only two mines, Landau III and Greenside, with a total throughput of 3,5 million tons per year. The annual capacity was increased to 7,7 million tons with the addition of Kleinkopje Colliery production from 1978, and a custom programmable control system based on a Motorola 6803 microprocessor was installed to cope with the higher throughput and complexity. This system worked well but rapidly became obsolescent, and its replacement was forced in 1989 when the hardware suppliers withdrew maintenance support.

The second-generation control system was based on standard hardware and software, although some custom coding was still necessary for the complex coal movement sequences. A programmable controller ("PLC") replaced the relay rack to handle motor control and interlocking, while two PDP-11 minicomputers and a "Cygnus" software package provided the operator interface, logging and accounting functions. This system was unusual in that the sequencing logic was programmed at the supervisory computer level, using the " CASL" language. The system had a mid-life upgrade when the PDP-11 computers were changed for MicroVax 3100 units, but this was essentially a "drop-in" operation with the aid of software conversion tools provided by the vendor. The system was successfully upgraded to cope with the additional production from the new Landau Colliery and an increase in capacity to 12 million tons per annum, but its replacement has now been forced by the withdrawal of maintenance support for the hardware and software.

Considerable advances in technology have occurred in the fifteen years since the second-generation system was designed. The PC is now almost universal as a supervisory machine, with a suitable SCADA package, while even PLCs now feature 32-bit processors, bus interfaces and Ethernet ports. The RLT operations are now divided amongst a number of networked PLCs, with the control sequences programmed at PLC level. The change to bus architecture instead of a star configuration has necessitated thorough testing and careful planning to ensure that the new system can be commissioned without delaying operations. The projected life of the mines feeding the RLT exceeds twenty years, but it is confidently expected that the use of standard hardware and software in the new system will enable it to be progressively upgraded in future without the need for radical redesign as in the past.

2. TERMINAL OPERATIONS

The RLT is constructed on a site near Blackhill, in the Witbank district. The railway tracks are configured as balloon loops, so that trains can be loaded and despatched on the move, without any need for shunting or reversal. Two "export" loadout stations are provided, as well as several stations for inland shipments. A central control room within the rail loops serves to control all the conveyors and rail operations, with satellite control rooms at each of the loadout stations. Administration offices are accommodated in a separate building outside of the rail tracks, connected to the control room by a fibre-optic link. Coal is delivered to the terminal on overland conveyors, one from each of the four main supply collieries. The RLT operator controls these conveyors, so that incoming coal can be routed to the correct stacker and stockpile according to source and grade, over thirty different coal types at present. Provision is also available to receive coal by road if necessary.

When the operator is notified of the expected arrival of a new train, he first consults his production schedule to determine what coal is to be loaded and then sets up the required batch(es). He enters the coal type, source stockpile, loadout station to be used and the mass to be moved into his computer terminal. The system then responds with a suggested route, detailing all the conveyors, floppers and transfer points to be used. The operator may accept this route, or he may specify a particular item of equipment to be used, possibly because of maintenance or scheduling constraints, and the computer will offer alternative routes that may be used. Over 600 routes are possible, but only about 150 of these are programmed for normal use. When the selected route becomes available, i.e. because none of the items of equipment are in use by another route, the operator can then initiate the batch transfer to the silo of the loadout station and loading of the train can begin as soon as the first wagon is in position. Export trains today typically consist of 100 wagons, each with a capacity of approximately 84 tons of coal. Spoornet imposes stringent restrictions on the mass loaded per axle, per wagon and per train in total, and a two-flask loading system with its own dedicated controller is employed. Gates above the first, larger weigh flask allow it to fill rapidly, and the coal is then weighed and discharged into the rail wagon as the leading end passes a photoelectric sensor. The loadout controller calculates the required mass to make up the rest of the wagonload, and this is measured accurately in the second weigh flask and discharged into the trailing end of the wagon. Each wagon has a transponder to identify its vehicle number to the loading system so that a complete record of all consignments can be generated automatically. When loading of the batch is completed, any remaining coal in the silo is removed on a purge conveyor and returned to its original stockpile. Note that a train may be loaded with more than one type of coal, each batch being run and loaded in sequence according to the production schedule. On completion of loading, the despatch documents are automatically printed for issue to the train driver, while copies are sent to Spoornet and to RBCT. The control system keeps a record of all coal movements, and daily, weekly and monthly reports are compiled for accounting purposes.

3. COALFLOW MICROPROCESSOR CONTROL

The original control system for the RLT, installed in 1976, conformed to the typical standards of Anglo American mines at that time. A custom-made, curved "banana" control desk provided the central control room operator with switches and ammeters for all the drives to be controlled. The status of all equipment was indicated on a large mimic occupying one wall of the control room, facing the operator. A relay rack mounted behind the mimic carried an interface card for each drive, 192 in total, to handle inputs from the desk, outputs to the mimic, basic interlocking and the interface to the motor control centres ("MCCs").

This system was modified in 1978/9 to cater for the increased complexity arising from the addition of Kleinkopje Colliery as a client of the RLT. Two 9'' (225 mm) monochrome monitors were fitted to the control desk, each with an associated keyboard. These keyboards were hand-painted and lettered to indicate different functional groupings of the keys. A Motorola 6803 microprocessor, programmed in Assembler, drove each keyboard and monitor. A custom, multitasking operating system for the microprocessor was written by the software project team, incorporating dynamic allocation of RAM memory to allow the concurrent control of several routes as well as the keyboard and screen handling routines. Data logging and reporting functions were provided by a Hewlett-Packard HP1000 minicomputer, using a RS-232 serial link from the

6803 microprocessor. A database file on the HP1000 held details of all the permitted routes, together with a cross-compiler to output sequences to the microprocessor in Assembler code. Drive status information was obtained from the relay rack, using an input/output card incorporated in the 6803 rack, the relay rack being retained to provide drive interfacing and interlocking as before. One printer was used to prepare consignment notes for each train, on multi-part pre-printed stationery stock so that the top copy could be issued to the train driver and others sent to the railway administration, RBCT and the RLT offices for filing. The same data was output to a tape punch that produced a paper tape in 7-track Telex format for transmission to RBCT. The entire system was designed and programmed in-house by a team from Anmercosa Computer Services Limited, a wholly owned subsidiary of the Anglo American Corporation. The concept of controlling material routing by microprocessor was considered novel at the time, and a South African patent, no. 80/4447, was granted in respect of the idea.

Some teething problems were experienced, as might be expected, but the system generally worked well and was accepted by the operating staff. Coal dust is conductive, so regular cleaning of PC boards and tape drives was necessary. Interference on the serial data link to the RLT administration offices was often experienced as the cable had to pass under the electrified railway line, and this problem was not really solved until the advent of fibre optic cable many years later. Motorola ceased production of the 6803 microprocessor in 1984, but the installed unit proved very reliable and the spare was not required for production use. A system upgrade was effectively forced by Hewlett Packard, who advised the RLT that they would discontinue all support for the HP1000 minicomputer after 1988. A number of the electronic cards in the relay rack had failed and spares were difficult to obtain, so a complete system replacement became necessary since operations at the RLT could not tolerate lengthy interruptions due to an unreliable control system.

4. CASL AND CYGNUS

Design of a new control system for the RLT had to take a number of factors into account, particularly ease of maintenance, cost and reliability, as well as a strategy to maintain throughput during the changeover. Several new coal mines had been developed by Anglo American during the 1980s, with a relatively standardised control system architecture based on the use of distributed PLCs and a centralised, redundant supervisory system, and this general design was adopted for the RLT. Engineers, technicians and programmers were familiar with this type of equipment, and it had proven to be robust and reliable in operation. An in-house team, from the Control and Instrumentation Department of Anglo American's Central Technical Office, again handled design, specification, project management and commissioning. A new mine, to be known as Landau Colliery, was planned to replace the declining tonnage from the Landau III mine from 1990 onwards, and the new control system was designed from the outset to accommodate the additional routes required.

The field instruments, cabling and marshalling were generally in good condition and did not need to be replaced, but each and every circuit had to be tested and checked against the available documentation, which was updated where necessary. Since the plant already had a centralised architecture, due to the use of the relay rack, it made sense to use a single, central PLC and a Siemens S5-135U was selected for the purpose. As before, the PLC provided the motor control and interlocking functions. Plug and socket connections had been used to interface the relay rack cards to the MCC interface cables. During the weekly maintenance shutdowns, a T-piece connector was inserted between each plug and the corresponding socket and new cables were made up to connect them to the PLC. This enabled the new control system to be connected in parallel with the existing so that it could be thoroughly tested on-line before going "live", the PLC outputs being disabled until the changeover.

The requirements for a supervisory system were considered to be too large and complex for the PC-based packages then available, so a minicomputer solution was chosen. Two SMS 1000/40 units, essentially PDP 11/73 equivalents, were connected in warm standby mode through a serial switch unit, allowing the operator to switch between machines in the event of a failure without having to call out a technician. The operator was provided with two new 19'' (483 mm) colour graphic screens, together with two customised membrane keyboards. An outline mimic diagram of the plant was printed on each keyboard overlay, so that the operator could go directly to the view that he needed to see without having to navigate through several layers of menu. The "Cygnus" package from AECI Process Computing ("APC") provided the basic software platform, handling both the operator interface and the data logging and reporting functions previously carried out in the HP1000. This package was written in RTL/2 and had proven reliable in a number of previous applications on Anglo American mines. As noted previously, the route selection process is very complex, due to the number of possible combinations of equipment that may be used, so it was decided to program this application in a high-level control and sequencing language known as CASL. All possible routes were programmed and stored, although only about 150 of them were enabled for routine operator use. As this was the first application of CASL for the company, the programming was contracted out to APC although subsequent systems were configured in-house.

The new PLC and supervisory system operated in monitoring mode in parallel to the existing system for a period to enable the operators to familiarise themselves with the new keyboards and graphics. Arrangements were made to obtain the plant for a day during a maintenance shutdown and the old system was unplugged. The new system was enabled and tested to verify that it was in fact able to control all the drives and equipment, and then the original system was reconnected. This test proved that, should there be problems in commissioning the new system, it was possible to revert to the original system in a period of less than two hours. Although ambitious, it was agreed to attempt the final changeover to the new system during a normal Sunday shutdown, and this was duly achieved on 7th July 1989 with no loss of production. Some minor problems were experienced, particularly as some mechanical modifications were made to the plant at the same time, but these were resolved before the deadline to use the option of reverting to the old system was passed.

The system has continued to operate reliably into 2003, although modifications and upgrades have been made over the years. Additional PLCs have been introduced in new areas of plant as the capacity of the RLT has been expanded, with serial links to the supervisory system as before. The two SMS computers were replaced by MicroVax 3100 machines in 1994), the existing supervisory system being ported to a new version of the "Cygnus" package by APC. The PDP-11 architecture was becoming obsolete, and the change to a 32-bit Vax system brought benefits in terms of speed and disk capacity. In particular, boot-up times were reduced from around 30 minutes to approximately 5 minutes, a significant saving when trying to recover time lost in a breakdown situation. However, as with the original system, hardware obsolescence and the withdrawal of software support have now forced a major redesign of the system. The Digital Equipment Company, manufacturers of the Vax range of computers, and also the earlier PDP ranges, was taken over by Compaq in 1998 and subsequently merged into Hewlett-Packard in 2002. While there is still a large installed base of Vax equipment, factory support is no longer available. APC have also gone out of business, overtaken by the trend to mass-produced SCADA packages operating on PC-based platforms. Former members of APC have continued to provide support services, but the very small number of CASL systems in South Africa has made it difficult to justify retaining expertise in this language and left the RLT system vulnerable to any failure.

5. THE PC ERA

With the declining support for the ageing Vax equipment, as well as the "Cygnus" SCADA system, investigations were made into a further upgrade for the RLT system. The decision was taken to use a PC-based system for the operator interface, with the sequence control devolved to the PLC level.

Given the fact that the site was now well established with Siemens PLCs, and the fact that site personnel were competent in maintaining both the Siemens software and the hardware PLC components, it was decided to replace not only the Cygnus SCADA system but also the now aging S5 PLCs with more modern Siemens S7 units. This ensured that maintenance staff were able to adapt to the new PLCs with relative ease.

As with the previous system replacement, a key element of the project design was to ensure that production was maintained during the changeover phase. This was further complicated by a change in network architecture from a 'star' configuration using point-to-point RS-232 links to an Ethernet bus system, which precluded interfacing the new PLCs to the existing SCADA, or vice-versa. The new system was constructed in parallel to the existing, with signals piggy-backed using temporary connections. Rigid software testing procedures were adopted to ensure predictable start-up when the new system went live.

The heart of the new system is two PC based WinCC SCADA redundant servers communicating over Ethernet to the main S7-400 PLC, and also to several smaller outlying S7-300 PLCs. For the initial phase of the project two remote SCADA clients were also installed. Ethernet radio links were also installed to the stackers and reclaimers, primarily for monitoring purposes.

Management structures in the company had also changed in the intervening years and project development was outsourced, although staff from Anglo Technical Division ("ATD") continued to provide a Quality Assurance service for the software component of the project.

A major consideration for the replacement system was the methodology of adapting the CASL sequence components for the new system.
The RLT at this stage had some 136 possible routes programmed into the CASL sequencing environment, with a maximum capability of over 200 routes.
Use of an open systems architecture was considered desirable to aid in future maintenance of the system and it was decided to use the standard Siemens Graph 7 software for the sequencing solution. This meant that the sequences moved from the SCADA system down to the PLC level, but ensured ease of maintenance and long-term support. In addition, after detailed discussions with operations personnel, the number of available routes was further reduced to 80.

Rather than hard code 80 sequences into the PLC, a system was devised that utilised seven main sequence templates or "jobs" that reference look up tables with associated equipment "device" numbers. These jobs are then "loaded" with the device numbers of all equipment in the route from the look up tables - all within the PLC software environment.

Each job can only have one source and one destination, but can utilise many routing options, up to 30 different routes in some cases, to transfer between the two. Ultimately, the operator's choice of source and destination determines the job that will run, and the choice of available routes determine the specific look up table of devices to be used.

Once a piece of equipment or device is loaded into a job it is flagged as "in use" and hence not available for other route options. Available route options at any given time are clearly indicated at the SCADA level, and this together with "coal type" tracking ensures that the operator has a clear indication of plant status. The "coal type" tracking is achieved by means of coloured bar graphs above the conveyors. Batches on up to 5 main routes can be run concurrently with full tonnage accounting.

Another important aspect of the project was the changeover methodology so as to maintain the operation of the plant but also ensure adequate testing of both hardware and software components and associated interfaces.

Standard front end software modules originally developed by ATD formed the core of the PLC software. Thin slice testing of the most complex route structure was performed at an early stage of the project to validate the sequence design methodology and the interface to the operator. Full integration testing was carried out at the end of the software development phase – all low level devices and all 80 routes were repeatedly tested.

For the implementation and commissioning phase, all PLC inputs were wired in parallel between the existing and replacement PLCs for monitoring purposes, with the main PLC being mounted temporarily outboard of the PLC cubicle. Correlation of all input statuses between the two systems was then carried out on the live plant. Drives were individually tested temporarily by swapping outputs over between the two PLCs on maintenance days. Once all devices had been tested in this manner, all the outputs for the entire plant were eventually changed over to the new PLC, but still leaving all inputs wired in parallel.

Final consideration for a smooth system changeover involves adequate operator training and buy in. Several sessions were held with operators on site to ensure adequate knowledge and familiarity with the system prior to changeover.

The changeover was accomplished on April 22nd, 2003, with minimal downtime due to the rigorous pre testing of software and hardware components, both during the integration testing phase and the commissioning phase. This, together with a dedicated site team of experienced personnel, ensured a smooth changeover to the new system. The system was run in this parallel state for a period of a month to ensure that there were no residual problems, and then the old PLCs were disconnected permanently, and all temporary wiring tidied up.

Operators have had little problem in adapting to the new system and general comments received have been that they find the new system more user friendly.

6. 24 YEARS OF EXPERIENCE

The original 6803-based system served for approximately 10 years, while its successor operated for no less than 14 years, albeit with a mid-life upgrade from PDP-11 to Vax computers. No unplanned downtime was incurred during the system changeovers, and subsequent downtime due to system or equipment failures has been negligible. It is noteworthy that both major system upgrades were forced by withdrawal of hardware support and not because of any defect in the systems. While today's system provides better ergonomics for the operator and more sophisticated reporting and fault diagnostics, it is, in principle, still performing the same functions as the original 6803 microprocessor system. The latest PC/PLC system is based on standard hardware and software, and it is hoped that this will provide an incremental upgrade path in future.

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