Today's industrial plants are becoming more difficult to control as they become larger and more complex. Consequently artificial intelligence (AI) technologies, specifically expert systems (ES), are being used to help operators perform supervisory and control tasks in a more reliable and efficient way, thus going a long way to help cope with these control issues.

The expert systems which encompass process knowledge, act as "super operators", assisting and performing all the mundane and highly tedious jobs, such as monitoring of thousands of plant variables, evaluating their trends and interpreting their behaviours and alerting and helping the operator where required. This technology is mature and running in many plants, improving performance and bringing many other benefits to the plant.

The problem - complex industrial processes
Industrial plants are becoming more difficult to control because they are becoming larger and their accompanying processes more complex. When we couple this to the highly competitive nature of business in general, it can be seen that to be competitive and achieve optimality is a major challenge.

The key - operators
The key to the operations of these plants is still the operators and there is an increased burden on operations staff especially in the South African context where there is a serious shortage of skilled labour and expertise. Operators are being assigned larger areas of responsibility as well as many other tasks to perform, and are thus thrust into positions where they are fighting a losing battle against the odds.

Information overload
A major contributing factor to the operators' problem is that there are just too many interacting complex processes with too many variables and accompanying issues to watch and control. This is an unintended consequence of installing powerful supervisory control and data acquisition (SCADA) systems and the many instruments available. Compounding the situation is that the processes are also run closer together in excess of their design capacities with higher volumes as a result of scaling up to achieve economies of scale. The operator is always under pressure to ensure that designed capacities and production targets are at least met if not exceeded.

Adding to their difficulties, is that there is generally little understanding from a first principle point of view of exactly how the processes work, and the understanding becomes less as newer and bigger plants are built. Add in the "just in time" (JIT) philosophy now being applied to continuous processes, environmental compliance, safety and social issues, running a plant is a hugely sophisticated task where one mistake can now be more costly (and deadly) than ever before.

The plant interface
SCADA or distributed control systems (DCS) are in general the interface between the plants and the operators. This is the primary tool with which operators and managers try to co-ordinate and control the processes on their plant.

The increasing sophistication of SCADA is also contributing to the operator's problems
Although generally quite successful, especially when compared to the previous mimic screens etc., the increasing sophistication of SCADA is also contributing to the operators problems which can be summarised as information overload, where quite simply:

- There is too much information from too many variables given to the operator. For example, the new Profibus type motor drives are incredibly powerful and have a huge number of I/O which are very useful, but in fact during operations confuse the operators.
- SCADA systems generate too many events and too many alarms. The decision as to which alarms are important and which are not, is a huge area of debate in its own right, and has spawned a very interesting side business of "alarm management" or "alarm rationalisation". The bottom line is that most alarms go unread or are ignored. Only after the fact (usually during the post-mortem) are these huge databases possibly sifted for clues as to what went wrong. This itself can waste a lot of time and cost a lot of money.
- The information as arranged in SCADA graphical user interfaces (GUIs) is not well presented and actually confusing. There are too many screens, too many icons, too many colours, too many trends - most of which are hidden. Even more interesting is the tendency to use the new Windows multimedia capabilities to the extreme which is proving to be totally counter-productive. Arranging screens with trees does help but again this and other GUI mechanisms does not solve the problem of information overload.
- There are too many interacting processes that are difficult to understand. Even the experts have problems here, especially as most processes are multivariable, non-linear and behave in a non-intuitive way. These process problems and knowledge of these idiosyncrasies are only apparent when the plants are pushed to the edge, and are inevitably forgotten when things go wrong.
- The SCADA GUIs are naturally limited in physical size and what can be displayed at any one time, and thus the process itself becomes difficult to represent in the GUI. One can compensate with many screens or by huge wall displays, but again the question is 'who is scanning and watching all those screens and all those wall displays which can span hundreds of meters?'

Compounding the above is the fact that operators are human - their scope of responsibility is often too large, shifts are too long, they get tired, and are not well motivated. There are too many goals - operators must
maximise production and efficiencies - all within a multitude of mechanical, safety, and environmental constraints.

Thus at best, decisions made to perform basic control (never mind optimise), are in general just sufficient to maintain production, and hopefully meet minimal safety rules, quality control and environmental objectives.

Solutions

There are many solutions to try and help the operators and improve their performance. These range from better training and education, better SCADA GUI design, a holistic approach to operator well-being and motivation, and the use of advanced computer technology.

Advanced technology solutions range from the obvious advanced process control (APC) and optimisation systems, which are a high level and provide for the optimisation and co-ordination of the various processes and in some cases the plant as a whole. Others include intelligent SCADA systems based on artificial intelligence. That is what this paper is about.

Manual and low level control still holds the key

As mentioned above, SCADA systems provide the basic low level means for control of a plant and its processes. Although APC goes a long way to solving the problem of complex plant control and optimisation, it cannot be effective if the base layer control is not in place and operating well. However even one below the base layer control, basic manual control operations still hold the primary key to a successfully running plant.

It is interesting to note that many studies and surveys have shown that avoiding or minimising abnormal conditions or plant trips by operators add more to the bottom line than APC. Thus a stably running plant with no abnormal conditions, generally achieved by the operator with basic layer control help is where one should not lose momentum in terms of effort and improvement.

Consider the aircraft analogy: The APC is the autopilot but as with aeroplanes, one cannot do without a human performing manual control i.e. take-off and landing, skirting around thunderclouds, and taking evasive collision control - the equivalent in industry being startup, shutdown, and emergency action. It is interesting to note that even whilst a plane is in stable flight under auto pilot control, the job of the pilot is still to continuously scan the instruments, and to verify the radar by examining the weather outside, in order to identify, confirm or predict problems before they occur. Occasionally the auto pilot will change course, the pilot will check this and from time to time tweak and adjust. He will scan only a few variables, those which directly affect safety and those central to reaching the destination.

From time to time the pilot will scan all instruments in a systematic way. This requires discipline for which they are paid a lot of money. But pilots are human too, and in fact to help him, a pilot has a co-pilot reading checklists and performing the mundane tasks. Also in a plane most alarm indicators are off and virtually invisible. Only when alarms occur do they become conspicuous and demand immediate attention.

It is interesting to note that when air accidents happen pilots are most often blamed. Even in an aeroplane with its well-paid pilot and co-pilot (never mind in a plant), there is an obvious need for further assistance.

The ideal operator

In summary: like pilots, we note that the ideal operator constantly needs to scan and monitor the plant, irrespective of whether APC is active or not. He needs to be able to review those primary variables crucial to his operations, and all the important ones must be visible. When necessary he needs to be able to see further detail. He must be able to absorb and understand trends and behaviours. He must correlate, validate and reconcile, with plant states now and in the past. He must calculate, approximate, infer and reason.

All a pretty tall order!

Hence the motivation for more useful and intelligent SCADA or basic control, where advanced technology can be applied to assist the operator see what is happening, focus on problems, infer, conclude and avoid those costly abnormal conditions, reduce trips and do all the operator tasks more effectively and efficiently. See Fig. 1.

The super operator

One can think of intelligent SCADA as a “super” operator or a tireless experienced plant expert that can do all the mundane operator tasks without missing a heart-beat or getting fatigued. When problems happen, it alerts the operator.
advises remedial actions and possibly even performs them. It also acts like a supervisor checking the operator or acting like a “collision detect” system on a plane.

The technology is based on the use of artificial intelligence or AI. This includes technologies such as artificial neural networks, machine vision, and expert systems.

We have found in particular the expert system to be extremely useful in assisting the operator to do his job better. It can perform all the mundane tasks such as monitoring the plant and all its thousands of variables, in real time on a continuous basis. There is no risk of boredom or fatigue causing the operator to miss spikes, glitches and other variable performance signatures. The expert system will do what is basically impossible for the human.

Intelligence and expert systems

There are quite a few definitions of expert systems and intelligence. For the purposes of this paper the key differentiating properties of such systems are that they have knowledge and are intelligent.

- Knowledge can be thought of as a body of facts and principles accumulated by mankind in the course of time.
- Intelligence can be thought of as the ability to reason or infer with the knowledge.

Thus an intelligent system has mechanisms for acquiring and storing knowledge and then working and reasoning with that knowledge.

It must be emphasised that data and information are not knowledge. Data can be a set of water temperature readings as stored in a database. Information can be thought of as the trending of that data and the fact that the temperature is increasing.

An example of knowledge could be the rule that concludes “If the temperature of the liquid increases to above 100°C then we can conclude it will boil”. Each rule consists of an if part called the premise or antecedent and a then part called the consequence or conclusion. When the if part is true, the rule is said to fire and the “then” part is inevitable - it is considered to be a fact. Note there is no “else”.

It must be pointed out that a system which can process “If then else” statements does not make it an expert system or define it as intelligent. One definition of the expert system is that it has the ability to store the rules as “data” as opposed to it being part of the program.

When the expert system infers or processes knowledge it uses knowledge to make conclusions or make decisions. In the inference process, the inference engine evaluates or fires a set of rules, and then moves up or down the rule tree to come to a conclusion. This is called forward or backward chaining and is not necessarily deterministic.

In the context of an intelligent SCADA, such a system has embedded sets of rules that convert process data into trends or facts and then use them to fire rules to determine the state of the plant. This is then used to come to conclusions or make decisions to aid the operator.

Some typical expert systems tasks

Some of the tasks performed by real-time expert systems (ES) in SCADA applications include:

- Scanning and monitoring every variable on a plant, all analogues and digitals. The ES checks their validity, performs data validation and data reconciliation, (mass and energy balances) and alerts the operator to any problems or potential problems.
- Checking the validity of the basic SCADA/PLC alarms against its own interpretation.
- Searching for and identifying abnormal conditions. This includes both fast moving dynamics which may be missed simply because they are not being displayed, or are within alarm limits, as well as slow moving dynamics where things can take hours or span many shifts.
- Examining multivariable conditions and potential process problems. Process problems are generally diagnosed on the basis of a whole set of evidence - patterns in sets of data. The expert system, which by definition includes fuzzy logic, as well as neural networks is extremely good at picking up and identifying such states which are essentially “images”.
- For example - only when a few temperatures and pressures move together in a particular way does it indicate something weird or a problem. However when that state is identified, maybe some additional information or data such as more temperatures and some flows need to be looked at also to confirm that a problem state exists.
- Filtering and consolidating plant data into summarised or simple plant states or more useful summarised descriptions of the plant. This is very useful for the operator who may only want to know whether a unit or train is OK or in a fault state and how its condition relates to the rest of the production or supply chain.
- Sorting and arranging, information, events and alarms into groupings that make sense for the various users or operators. Production people may want to know about outputs and consumption of raw materials, whilst power engineers want to know about total and specific electrical power consumption issues.
- Advising the operator where there are problems, or where potential problems could arise in the future. Monitoring the operators response - does the response conform to constraints as defined by management or the plant experts? This is done for example by monitoring the setpoints or buttons pushed by operators and validating their activation within constraints as defined to certain states, as well as the operator’s personal profile, the plant performance during the last few minutes, etc.
- Focusing the operators attention on the problem areas and automatically bringing up the relevant screens for his attention. This is an extremely important function, as valuable seconds could be lost by the operator trying to navigate to a certain screen.
- Taking automatic corrective action.
- Monitoring the performance of the operators themselves for management performance audits as part of a general process performance evaluation strategy.
- Logging alarms or events intelligently (in a way that facilitates easy analysis later).
Typically the intelligent SCADA also does the following: As problems occur or a likely problem is identified, the system will evaluate the potential risk of this problem together with other events or problems, prioritise them, alert the operator and present them in a clear and unambiguous way. This is called automatic operator attention focusing. Built into the system are tolerance behaviour checks where, if the operator ignores or fails to attend to the problem quickly enough, the system escalates the priority, and possibly signals the supervisor or starts flashing more obtrusive red flashing screens.

Implementation

Intelligent SCADA or expert systems are implemented in many topologies and configurations – one common one being that it is totally invisible to the operator. The operator thinks he or she is operating the plant from a normal SCADA. However under the hood, the inference engine is chugging away in real time using domain knowledge and expertise to evaluate plant states, cycling through check lists at high speed or reacting to dozens of asynchronous events per second in real time.

On some plants the SCADA GUI is replaced by an expert systems GUI, depending on the technology being used as well as company policies in this regard. In some plants both GUIs are used.

Programming the knowledge

Putting knowledge into the system and verifying and testing it is an interesting exercise in its own right. This is generally product-specific, but some principles which hold are:

• Try to keep the number of rules to a minimum. The more rules, the more complex and difficult it is to verify the system.
• Use object oriented principles and programming (OOP) where possible. OOP allows for the creation of object hierarchies, where principles such as “inherence” and “abstraction” can be taken advantage of, all of which contribute to less (and simpler) rules.
• Use generic programming where possible. A generic rule is for example where one rule scans all 5000 variables on site to detect if they exceed some related set high value.

Knowledge paradoxes

Putting together an expert system is in reality not simple. The core to the system is knowledge which is based on the expertise and experience of people. Deriving this is a problem, because experts generally want to hold onto their knowledge which they deem important to their survival within a company. One needs to show experts that firstly, knowledge can’t be owned and secondly, the intelligent systems can actually help them do their jobs better.

Defining the knowledge required is itself can be ambiguous and risky. By definition, a problem and the knowledge surrounding it cannot be complete unless one defines the unknown together with the known. You therefore need to define what to do when you move in either direction. This means that at some point the system must know when to say, “I don’t know” and/or how to involve the operator to possibly complete the knowledge.

In addition, everyone has a different solution or interpretation of what defines a particular plant state or process problem. This seems to be an intractable problem. However, using the expert system helps to at least arrive at a consensus as to the right conclusion.

The power of the expert system is that all different conclusions can be put into the system, with their various degrees of belief as to their correctness. The systems will not only determine the conclusion, but also show how the conclusion was reached.

Management policy

It is important to emphasise that expert system rules and the way in which intelligent SCADA reacts to and interacts with operators is totally determined by the management and staff of that plant or corporation. In other words, how a problem is brought to the operator’s attention, how it continues to present it as time goes by and what to do if the operator ignores it is totally a function of the policies and rules of that plant and its people. What is sometimes difficult to specify is the degree of operator-computer interaction, and how much is automatic and how much is manual. This depends on safety standards and various other process issues. It also depends on how management views the risks surrounding automation versus manual operation.

Summary

Scada systems provide the basic means for an operator to monitor and control a plant. These systems have inadvertently created a situation of information overload. Exacerbating this problem is the fact that these plants are complex and difficult to control, while, at the same time, there is a general scarcity of knowledge and skills to absorb, analyse and use all this information.

To help ease the operator’s load and ensure reliable and better supervisory control it is becoming common to use artificial intelligence tools such as expert systems, these are being used as an intelligent SCADA or a “super operator” which does not fall asleep or miss any abnormal conditions. Such systems are either embedded in a SCADA or used as the actual SCADA itself and provide a reliable mechanism of continuous surveillance.

This intelligent SCADA is loaded with domain and process knowledge and in general performs all the routine, boring tasks that the operator usually performs, such as scanning thousands of process variables in a systematic way, in real-time inferring problems or potential problems.

This system then focuses the operator’s attention on the problem or enforces standard operating procedures, ensuring the abnormal conditions are easily identified in time, so that trips are minimised. This ensures that the plants run more reliably and consistently, resulting in numerous benefits.

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