OPTIMISING THE EFFECTIVE USE OF ENERGY IN THE FERROALLOY INDUSTRY THROUGH INNOVATIVE TECHNOLOGY

J.G. Roos[1] and A.M. Hearn[2]

[1] Project Manager, IST Otokon, 221 Garsfontein Rd, Menlyn, Pretoria, South Africa. E-mail: johanr@ist.co.za
[2] Technical Manager, Samancor Meyerton, South Africa. E-mail: tony.hearn@bhpbilliton.com

ABSTRACT

Energy consumption, being a large proportion of the input of the ferroalloy production process, can be measured in terms of the efficiency with which the energy is utilized and the effectiveness with which it is used. The efficiency of the usage of energy revolves around the specific consumption of the energy for the production of the alloy, which encompasses the thermodynamic aspects of the process and is more of a metallurgical function that will not be addressed further in this paper. The effectiveness with which the energy is utilized is determined by the optimisation of the electricity supply from the utility (in this case Eskom).

The South African electricity supply industry is on the brink of considerable restructuring, implying changes in ownership, structure and regulation. In other countries, however, restructuring has often seen higher prices. Owing to the diversity of growth prospects in South African markets, Eskom is turning to new market management and generation strategies. In future, Eskom will develop pricing strategies to increase demand from attractive customer segments such as paper & pulp, iron & steel, aluminium, and other metallurgical industries. There will be a broader spectrum of product offerings, including dynamic pricing options and demand-side management incentives.

In a future electricity market that will become more dynamic and demanding, it will become increasingly important for electricity consumers to optimise their electricity supply. There are many facets in optimising the electricity supply, which include optimal utilisation of the tariff, integrating energy cost management into the production planning process, implementation of demand-side management actions, modelling, scenario planning ("what-ifs?"), optimisation, maintenance scheduling coordinated with the tariff periods, etc.

This paper gives consideration to the status of the development of technology at the manganese alloy works of Samancor at Meyerton, South Africa in order to increase the effectiveness with which energy is utilized.

1. INTRODUCTION

Recent announcements by the South African government about restructuring of state-owned enterprises has led to growing anticipation about the commercialisation of Eskom, Africa's leading electricity supply utility [1]. These moves will open the door to private participation in the local electricity supply industry. Eskom's sole position in the market – alongside a plentiful coal supply and high-availability power stations - has ensured South Africa a cheap and stable supply of electricity. Upward pressures on price are, however, mounting steadily, as is evident from the recent announcement by Eskom management that the local electricity price is likely to increase at a rate above inflation. These pressures include the impact of Eskom's corporatisation, a strong government emphasis on the social delivery obligation of power producers, and a growing requirement for environmentally clean electricity.

Industrial consumers could off-set these impacts through a number of strategies, including: the better management of their electricity consumption through energy optimisation; the structuring of innovative electricity pricing options to preserve profit margins; and the development of risk management strategies to ensure long term access to clean, reliable and low-cost electricity.

A number of downward pressures on pricing, including an oversupply of generating capacity, are still in place to make South Africa a good destination for energy-intensive facilities to relocate to. There is still substantial surplus capacity in South Africa, and the introduction of competition in the industry will ensure that South Africa's energy prices remain globally competitive in the long-term.

The introduction of competition will more accurately reflect the dynamic relationship between demand and supply, probably causing prices to become a lot more volatile prompting large consumers, like those in the ferroalloy sector, to manage their electricity purchases more actively. The new electricity market will set new demands on large consumers that will, if they are active and alert, be able to take advantage of the competition. This requires that customers are flexible in terms of negotiation and decision-making, together with analysing different options regarding production, energy sources and contracts. The analyses must be both in the long- and short-term, and it will become necessary to integrate energy management decisions with production planning.

The changes in the electricity industry are leading to the development of market opportunities and competition in the field of energy management services provided by Energy Services Companies (ESCOs). Due to the dynamic nature of the developing energy market, players in the market, both the consumers and the ESCOs, should enhance their conventional energy management approach with innovative ideas and technologies in order to strengthen their market position. This paper gives consideration to the status of the development of innovative technology at the manganese alloy works of Samancor at Meyerton, South Africa, in order to increase and optimise the effective use of energy.

2. CHANGES AND OPPORTUNITIES IN THE ELECTRICITY MARKET

2.1 Recent Changes

The survival and growth of South Africa's economy is dependent on the international competitiveness of its industries. These industries face increasing competition from globalisation and will increasingly demand more flexibility from their energy suppliers. Restructuring of the electricity industry internationally followed a general trend towards a market structure along competitive lines, with freedom of choice and greater flexibility as clear objectives.

Large industrial users of electricity have been key to the liberalisation of energy markets worldwide as their large individual market shares give them buying power and they have, very often, formed themselves into influential industrial end-consumer groups. These groups have been the drivers for lower energy tariffs and many large users have taken to generating a portion of their own power requirements themselves. The result is that the energy utility sector is undergoing fundamental change around the world as markets are liberalised and government owned utilities are privatised. The energy market is facing new challenges including de-regulation of markets, third-party access and a free choice for electricity customers to choose among a large number of electric utilities. South Africa is following the worldwide trend giving rise to opportunities that will go a long way in ensuring that the economy remains competitive, particularly as regards the supply of electricity is concerned.

2.2 New Opportunities

Within a relatively short period of time the industrial and large commercial customers will be acting on the energy markets where, for example, the electricity price may vary hour by hour. In this dynamic rate there will be large variations between the lowest and the highest energy charges. The variations will be over the day and, in line with the international norm, also by season. The demand charges will also be differentiated and reflect actual constraints in the transmission and distribution systems.

The market will function with long-term contracts for base needs and shorter contracts for varying energy needs. Immediate electricity requirements, over and above the contractual purchases, will be undertaken in spot markets. In addition to the electric utilities supplying and selling the electricity, there will probably be energy brokers and traders who deal with short or long term contracts on power supply without having the generation, transmission or distribution assets.

The brokers will function by buying and selling electricity representing a third party and only take very short-term positions of their own. The traders, on the other hand, will buy or sell electricity as a means of speculating on the price of the electricity. Traders are willing to take on the price risks that other participants on the market wish to relieve themselves of. The informed trader actively gathers information, which he analyses better than anyone else, and then buys or sells contracts according to his analysis.

2.3 Eskom's Electricity Tariffs

South Africa has until recently been in a position where Eskom, the local utility supplying electrical energy to the different consumer sectors, had adequate capacity to supply their customers. This situation is rapidly changing due to various internal and external factors.

The most significant external factor is the socio-political objectives of the government, one of which is the so-called electrification drive, which entails the electrification of more than 1.5 million houses within a five-year period. This will accentuate the capacity constraint as a result of the peaky nature and poor load factor of the domestic load.

Over the years, as the national demand pattern for electricity in South Africa changed, Eskom has tried to signal to its bigger consumers the hours in which the system is lightly loaded and heavily loaded. Owing to the nature of electricity generation, particularly coal-based generation in South Africa, it is impossible to precisely match available generating capacity to the demand at any given time, resulting in periods of excess capacity (reserve) punctuated with periods of tightness of supply (shortfall). The shortfall periods are associated with higher risk of loss of load as well as the use of the most expensive generation equipment.

In an attempt to match the system capacity with the demand peak, the tariffs evolved from the Standardrate tariff with 24-hour demand measurement, to Nightsave with 16 hours of demand measurement during day time only, and the later Time-of-Use tariffs with a lower demand rate for 16 hours, but with differentiation between peak, standard and off-peak energy rates. A major constraint is that all these tariffs remain static for some time, usually a year, and are based on average cost and longer-term needs.

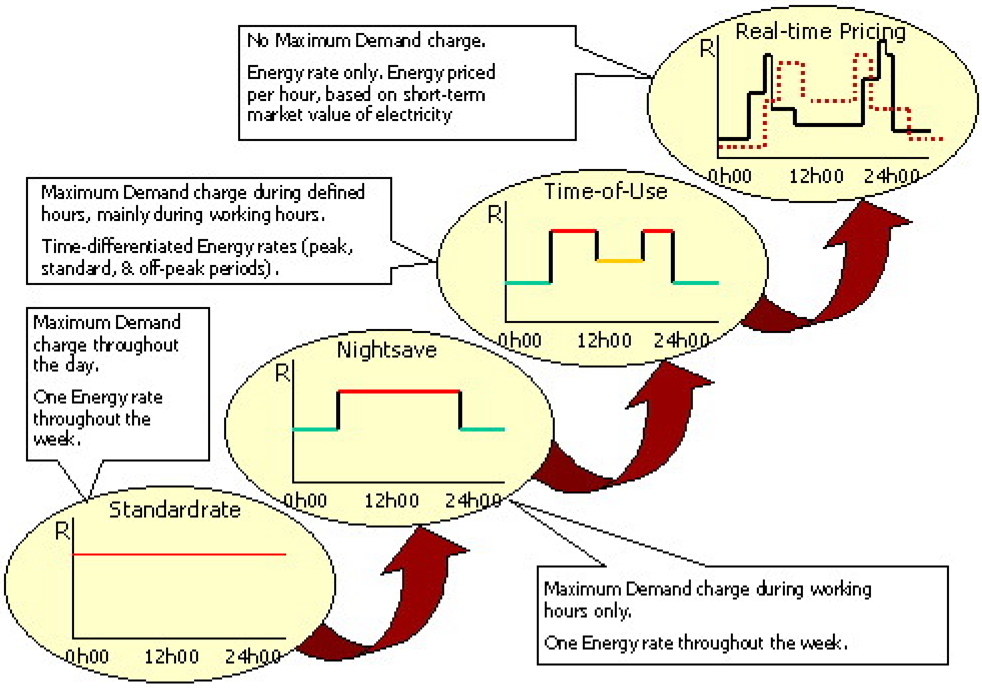

Figure 1. The evolution of Eskom's tariffs.

One of the ways of addressing this issue that is used by a growing number of supply authorities world wide, is to place a certain portion of demand on a flexible pricing regime. In this way flexible customers are able to respond to dynamic pricing signals from the supplier of the electricity and adjust their demand accordingly. Eskom designed a new dynamic pricing regime specifically to align customers' daily demand-side decisions with Eskom's short-term needs. This dynamic pricing regime is referred to as Real-time Pricing, or generally referred to as RTP. The evolution of the tariffs is illustrated in Figure 1.

Real-time pricing, or RTP, is a dynamic electricity tariff and can be seen as a forerunner of electricity prices in a competitive energy market. RTP is the pricing methodology that exposes customers' consumption decisions to the short-term value of electricity. The short-term value of electricity is determined by the Eskom Power Pool and signals the state of the Eskom system, with high prices during times of capacity and/or system constraints and, conversely, low prices when the system is lightly loaded or system slack. These values are communicated to customers one day ahead, leaving the customer to decide whether the customer wants to consume more energy during hours indicated by low prices and/or conserve energy during the hours the Eskom system is constrained.

By reflecting the real cost of electricity to the consumer through variable prices for specific - generally one hour - time periods, the utility provides the consumer with the information necessary to make economically sound load management decisions. An energy-intensive industrial consumer of electricity, faced with a certain demand schedule for his products, would try to adjust his production schedule to take advantage of electricity price differentials between different periods. By responding in a "positive" manner to the pricing signals, the consumer stands a very good chance of lowering his average electricity cost (c/kWh) over a billing month.

The magnitude of the consumer's demand response to these dynamic pricing signals will depend, apart from other technical constraints, on the economic value he associates with electricity at that stage, i.e. his price elasticity of demand. Price elasticity of demand varies with time because it is a non-linear function of various factors, amongst others the commodity price, and the current market demand for the commodity. There are a multitude of interdependent factors at play, not the least being the real-time price, making it difficult for the consumer to decide on an optimal production schedule to take advantage of the RTP pricing signals over a specific period of production. This difficulty increases with the size and complexity of the plant and the electricity pricing options in a deregulated market.

The complexity of this problem calls for the implementation of a knowledge-based decision support system to support the RTP customer to take maximum advantage of the varying pricing signals in an ever-changing environment of production targets and rules, market conditions, labour issues, plant constraints and maintenance planning. Knowledge-based decision support systems are computerised systems that contain a carefully selected amount of knowledge of the problem domain, and are used to support managers, engineers, and control operators to make better-informed decisions during their managerial, planning or control tasks. This will be discussed in more detail in a later section.

2.4 Demand-Side Management

The term Demand-Side Management (DSM) is used to describe the planning and implementation of activities designed by electrical supply utilities to influence the time, pattern and amount of electricity usage in such way that it will increase customer satisfaction and at the same time produce desired changes in the supply utility's load shape [2].

DSM was first used in the United States in the early 1980s. As an alternative to system expansion as well as a tangible means of providing customers with a valuable service, it was later adopted in the United Kingdom, Europe, and Australia. Today, DSM-associated initiatives are practised worldwide, although not necessarily referred to as DSM programmes.

In South Africa, DSM is still a relatively new concept to most. While Eskom formally recognised DSM in 1992 when integrated electricity planning (IEP) was first introduced, the first DSM plan was only produced in 1994. In this plan, the role of DSM was established and a wide range of DSM opportunities and alternatives available to Eskom were identified.

The current peaks in Eskom's national load profile are attributed to activities in all three load sectors (residential, commercial and industrial), but the biggest contributor is the residential sector mainly due to the rising numbers of newly electrified households, and although this meets the requirements of the government it unfortunately puts a strain on the utility's resources to supply the other load sectors.

Although, from an overall point of view, Eskom currently has surplus base load and peaking load capacity, it is forecast that the peaking load capacity will significantly reduce over the next five years and, in order to maintain supply of electricity in times of severe system peaks, additional generating capacity will need to be installed. A new peaking load power station is not only capital intensive but takes up to seven years to build and commission. In contrast, the advantages of DSM in displacing additional generating capacity are apparent in the fact that DSM programmes can generally be rolled out in less than 12 months. This, combined with the lower cost of DSM compared with the building of a new power station, makes it a particularly attractive load management option to defer the installation of new generating capacity.

The load target set by Eskom DSM to obtain the successful deferral of power stations over a 25-year period is 6,617 MW [2]. According to the DSM initiative this peak load reduction must be achieved in three focus areas, viz. the residential, the commercial and the industrial sectors. The DSM initiative also focuses on both load management and energy-efficiency programmes. The objective is to reduce the 24-hour base load by energy-efficiency projects, such as energy-efficient lighting, and to reduce or shift electrical load from the morning and evening peaks (07:00 – 10:00 in the morning, and 18:00 – 20:00 in the evening) into the off-peak periods by implementing load management systems.

Eskom has placed a financial value on each unit of load that a customer binds himself to shift in the evening peak and for this Eskom will fund the capital expenditure on energy-efficiency, load management and measuring equipment. The Energy Services Company (ESCO), which identified the project at a potential DSM site, will implement the project and be responsible for maintaining the project in order to ensure that the committed load reduction is sustainable. The benefit for the customer is the saving on his monthly electricity bill for which there was no capital layout. The benefit to Eskom is the capital expenditure deferral of building generating capacity as well as transmission and distribution lines.

The current load management actions in terms of DSM are targeted at the evening peak of weekdays from 18:00 to 20:00. The participating customer must commit himself on the amount of load reduction over a relatively long period of time, since this load reduction must be sustainable.

3. INTEGRATING ENERGY COSTS INTO PRODUCTION PLANNING

3.1 Introduction

Today most production companies have some kind of system for production planning and control (PPC). There are a large number of systems available on the market, and system performance and costs vary substantially. In order to manage the planning and control of production, today's PPC system is computerised. It serves as a planning tool for top management to make long-term decisions, and it is used on a weekly and daily basis to make up production plans on the basis of what is ordered or on any other criteria for the desired production. The PPC system is used to optimise the company's production, to optimise the use of existing capacity, to show where bottlenecks are, and to minimise inventory levels.

However, one important parameter that is not taken into consideration in most PPC systems is the use and the costs of energy. This is a great disadvantage in a world that, at many locations, is facing new and challenging conditions in the energy markets. Integration of energy costs into production planning seems to be a key missing point. Energy supply constraints are almost never considered as a part of the planning chain, with the exception of single applications on some limited steps of the whole planning process. In many cases the attitude toward the availability and cost of electricity is one of flicking a switch. The developments in the electricity industry will ensure that it is more dynamic than that.

3.2 Objectives

The two main objectives of integrating energy costs into production planning are to reduce the use of energy and to improve the competitiveness of the industry through cost reduction.

These two main objectives will lead to some secondary objectives:

- By developing and implementing a knowledge-based system that enhances the co-operation and interaction between the energy supplier and the industrial energy consumer there is a base for making the right decisions on what energy source to use, in what quantity, and at what time. This decision process is simplified by the use of modelling, simulation and optimisation tools, and the control of the energy system is assured by using a load management system.
- The modelling, simulation and optimisation modules of the integrated system will aim at the minimisation of the system cost, i.e. the sum of costs for all the studied cost components of the company. This might include labour costs, costs of raw material, energy costs, water costs, and the costs for not producing due to the implementation of load management actions (the so-called cost of unserved energy) although the targeting of energy cost alone addresses a reasonably large proportion of the total cost.
- There are environmental benefits as a long-term result of reduced and more efficient energy usage. The possibility of using a system for the tracking of carbon units and trading in them also exists.

3.3 Integrated System for Planning and Control of Energy-efficient Production

In many production processes, there is great scope to reduce the energy bills substantially by making use of integrated energy management techniques. Such applications will demonstrate significant savings with short payback periods. The key advance proposed by the concept is the integration of three management domains: utility-driven management of consumer demand, consumer-driven production planning and control, and consumer-driven energy-use planning and control. The basic approach is to integrate optimisation, simulation and control of energy systems with production planning and control, in order to arrive at a situation where the whole is greater than the sum of the parts.

In addition to cost reduction on the consumer side, the widespread use of such techniques, coupled with close integration between utility and consumer systems, will enable electric utilities to achieve their demand-side management (DSM) targets with consequential improvements in generation efficiency and fuel usage, and hence in environmental benefits.

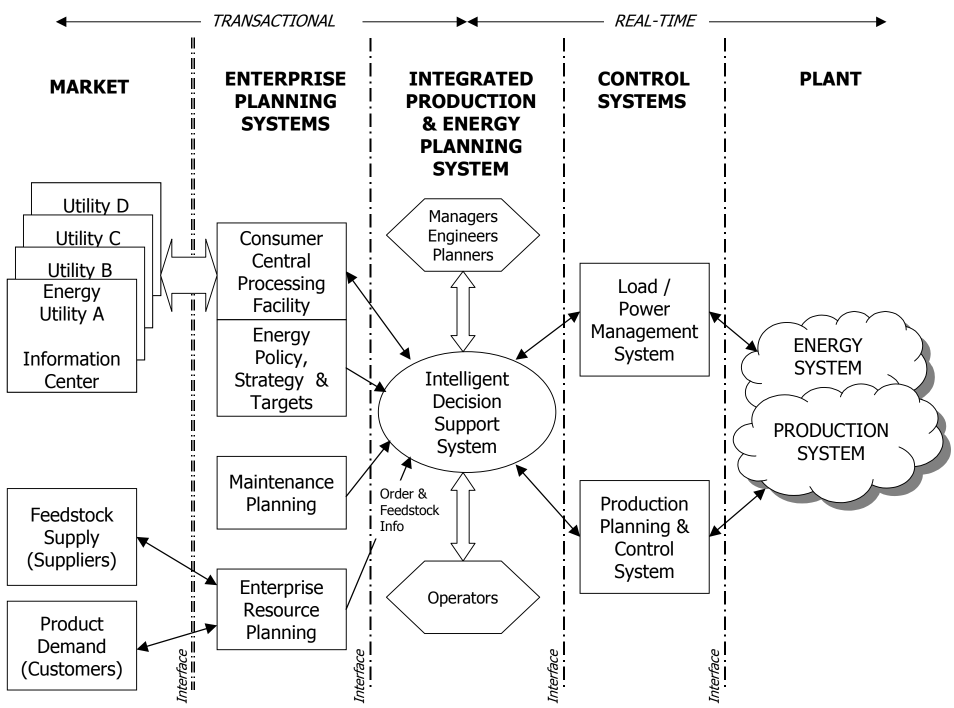

Figure 2. Architecture of an integrated production and energy planning system.

3.4 System Layout and Architectural Issues

Figure 2 shows a simplified model of an integrated system for optimal Energy Management and Production Planning & Control. In the centre of the figure is the core of the proposed integrated system, i.e. the Intelligent Decision Support System (IDSS), which contains all the tools and innovative technology to optimise energy costs within a confined set of targets, constraints and rules. These include energy targets from the company's energy policy/strategy, product requirements, plant constraints, production priorities, feedstock availability, alternative energy sources, maintenance plans and other plant & production rules.

There may be more than one energy supply utility, that is attempting to sell electricity, natural gas, oil, coal, LPG, etc. In a de-regulated electricity market there will be opportunities for the industrial consumer to choose to buy power from whatever utility that has the best terms for the power delivery. Contracts will be negotiated quite often, and it may be feasible to buy part of the company's energy needs from the spot market.

It is necessary for the industrial consumer that wants to take advantage of competition in a deregulated market to stay informed about all the facts that concern the company's short and long-term energy needs. This necessitates an interface between the supply utility's information centre and the industrial company's central processing facility (CPF) to avail the company (or consumer) present and future energy prices to carry out optimisation and simulation. As a corollary the utility requires, to facilitate supply planning, information on the consumer's actual and forecasted energy consumption, planned schedules, or his bids to buy energy from the spot market.

The IDSS has to come up with two outputs: a suitable production plan that is given to the PPC, and an energy management plan that is given to the load management system. These outputs need to take into account information from the CPF relevant to energy costs, and to allow for the operation of relevant load and power management strategies. For example, if there is scope to do so without affecting production deadlines, it may be possible to shift activation of some heavy load to a lower tariff period. Where an alternative energy source is available (e.g. a co-generating plant) an optimal schedule for the use of that source is produced, based on comparative energy costs and production requirements.

Integration between components and subsystems from different suppliers and in different domains can only be achieved if there is a clearly defined and well-accepted architectural framework for integration. In practical terms, the architecture is defined by a set of interfaces and protocols for communicating across those interfaces. There are three primary interfaces in the integrated system concept: the interface between the industrial company and the market (its suppliers and customers); the interface between the company's enterprise planning systems and the IDSS; and the interface between the IDSS and the control systems.

3.5 Management Commitment

The decision support tools for analysis of energy and material flows, including the optimisation, are very important. The use and application of these tools will increase the consciousness and awareness on the costs of energy and what the energy costs represent in monetary terms for the company.

The results will also indicate how the different production strategies (production plans) and the possibilities to control the energy use will affect the system costs. The change (reduction) of system costs will increase the competitiveness of the products or improve the net revenues for the company.

However, the value of the increased knowledge and the improved awareness is not fully utilised if the management's commitment to these ideas is not clearly stated. The top management must commit themselves to take this new information into account and to make sure that this new way of thinking is accepted throughout the organisation. Management must also dedicate resources to the integration process. It is important that these companies are organised so that the energy management departments work in conjunction with the production departments.

3.6 Implementation Guidelines

It is not sufficient to only have a definition of the architecture for the integrated system to be applied successfully. A major requirement is to have a set of guidelines for implementation of solutions. It is necessary to have a complete and reliable program for auditing regarding the production system, energy systems, production planning and control, organisation, business goals, etc. It is necessary to base the integration process on the actual production planning process that is used by the company today, on all levels of the company, from the boardroom to the engineer and the operation on the shop floor for the next shift.

4. INTELLIGENT DECISION SUPPORT SYSTEM

4.1 Introduction

Organisations first developed decision support systems (DSS) in the early 70's. At that time, they were a radical departure from previous computer applications that emphasized transaction processing and structured reporting. As the name suggests, a DSS focuses on supporting decision-making. They are widespread in organisations today, both as freestanding applications and integrated into executive information systems.

There are several ways to define a DSS, but the following definition is useful: [3]

> *A decision support system is an interactive system that provides the user with easy access to decision models and data in order to support semi-structured and unstructured decision-making tasks.*

The user is typically a manager or a staff member. A key part of the system is the software interface (also called the dialog) that makes the system easy to use. The system contains models (also called analytical aids) that are used to analyse the data that must be maintained and the integrity thereof be beyond reproach. The decision-making task supported by the DSS is a challenging one in that either the objectives or the means of achieving the objectives are unclear. The DSS does not make the decision, but rather, provides information that is used along with other information by the user to arrive at a decision.

Several modelling techniques for decision support have emerged over the last few decades: the symbolic approach (rules, case-based reasoning and fuzzy logic), the connectionist approach (neural nets), the evolutionary approach (genetic algorithms), and the inductive approach (machine learning). At the same time database technology, "data warehousing", and on-line analytical processing (OLAP) are making it easier to get at organisational data. These techniques derive their power only when more fundamental technologies are in place: telecommunication networks, database systems and desktops.

The shift toward decision support also reflects the changing nature of the work in business organisations. Increasingly, work is becoming "knowledge oriented". People have to work with information, which includes gathering, summarising, and interpreting it, in order to make decisions. There has been an explosion in the volume and variety of electronic data available to businesses, and, correspondingly, a huge need for systems that help business people make sense out of these reams of data. This has led businesses to develop systems that are smarter about how they condense and interpret data for the end user.

The growing number of "knowledge workers" in organisations will require systems that "know more" and "do more" in terms of accessing, summarising, and interpreting information. Knowledge workers will depend more and more heavily on these systems to help them make decisions faster or with a greater degree of confidence. This is the future of decision support in particular.

However, there is no framework, methodology, or technique that eliminates the need to think critically, creatively, and with curiosity about problems that one is attempting to solve. Intelligent decision support systems are usually components of larger systems, and ultimately, organisations. These techniques can be applied across the business sectors, from financial management, marketing, resource management, to integrated production/energy planning and management.

4.2 Architecture

The core of the proposed integrated production/energy planning system is the intelligent decision support system (IDSS). The IDSS primarily consists of two components, i.e. a knowledge base and a set of supporting tools, as is shown in Figure 3.

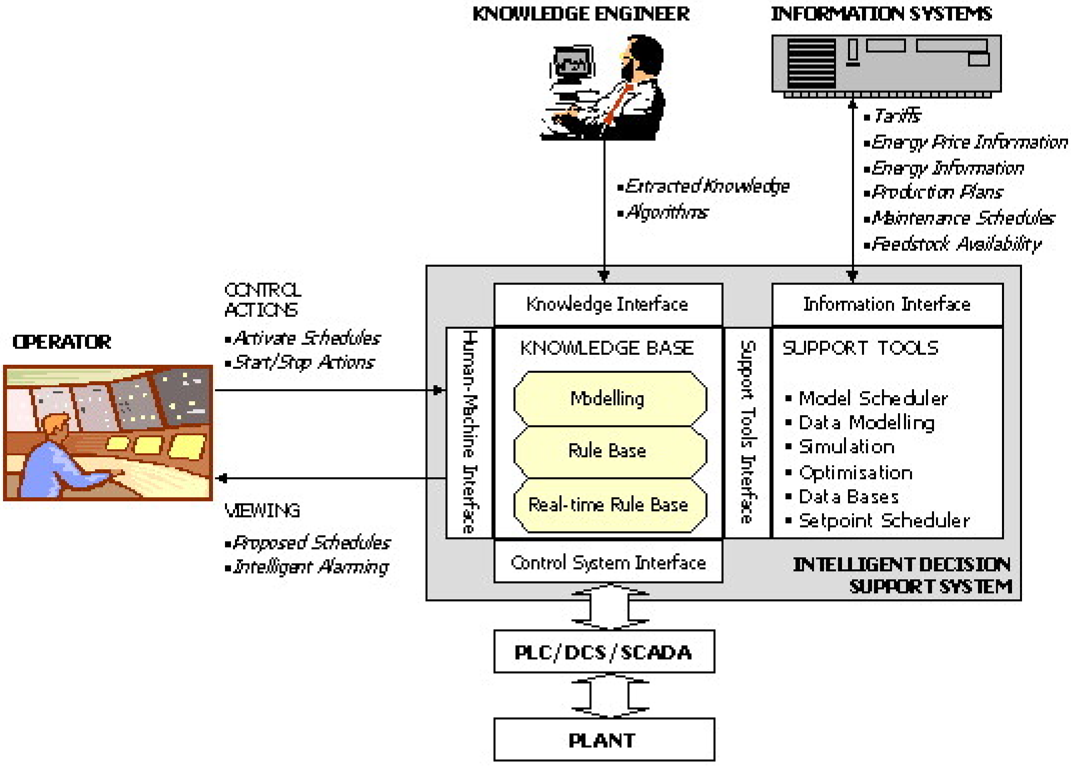

Figure 3. Architecture of an intelligent decision support system in an integrated production/energy planning system.

The computerised model of the integrated production and energy systems is built from knowledge extracted from plant personnel and experts during the auditing phase. The Knowledge Engineer (KE) is responsible for populating the knowledge base in a given application. He has to possess the interpersonal skills necessary to win over a plant expert and extract the knowledge. The KE must work with the eventual users of the system to assure that the system is designed properly from a user-interface perspective. Eventually the knowledge base will be populated with production, plant and maintenance rules that will be used when production schedules are optimised.

The knowledge base relies on the support of a number of tools in order to suggest an optimal production schedule to the operator via the human-machine interface (HMI). These support tools include Data Modelling that presents historical plant behaviour through historical data, Simulation, and Optimisation. Databases are necessary to store historical data as well as new production schedules. A Model Scheduler is necessary to determine and control the sequence of events of the whole data preparation, modelling, optimisation and production scheduling events. When the proposed production schedules are approved and activated by the operator through the HMI, a Setpoint Scheduler communicates the new approved setpoints via the control system interface to the production control system, where they are implemented as real time adjustments.

The information system, as shown in Figure 3, is the source of data for use by the support tools. Information from the production model, as considered in section 4.3.1, is an important input as is all the external energy related information. In order that optimal use is made of the market-model, as proposed for the restructured electricity supply industry, for the supply of electricity it is necessary that the communication hardware with external sources of information be robust. Although not directly an issue for discussion in this paper the restructuring of the electricity supply industry is an important factor to be considered in the model. The details will not be considered further save to note that the model must be flexible in order that it can be adapted to cater for the final format of the industry.

4.3 Functionality

4.3.1 Production and Energy Model [4]

The industrial production and energy system model composes of nodes and branches, representing production processes and flows of energy and material, expressed on an hourly basis. Energy flows represent steam, electricity, hot water, etc., whereas fuel (e.g. oil) is represented either as a material flow or an energy flow.

Industrial production is represented by a material flow, which is distributed to the production processes, through the input node (nodes 4 & 5 in Figure 4 below, which is shown as an example), passing through the process nodes (nodes 7, 8, 11, 12, 13) where an energy demand is generated according to certain conversion functions, and finally aggregated in the output nodes (14 & 15). An energy conversion node (6) converts energy from one form to another. In the example below in Figure 4 gas is converted in a steam turbine generator to electricity and steam according to a certain conversion function.

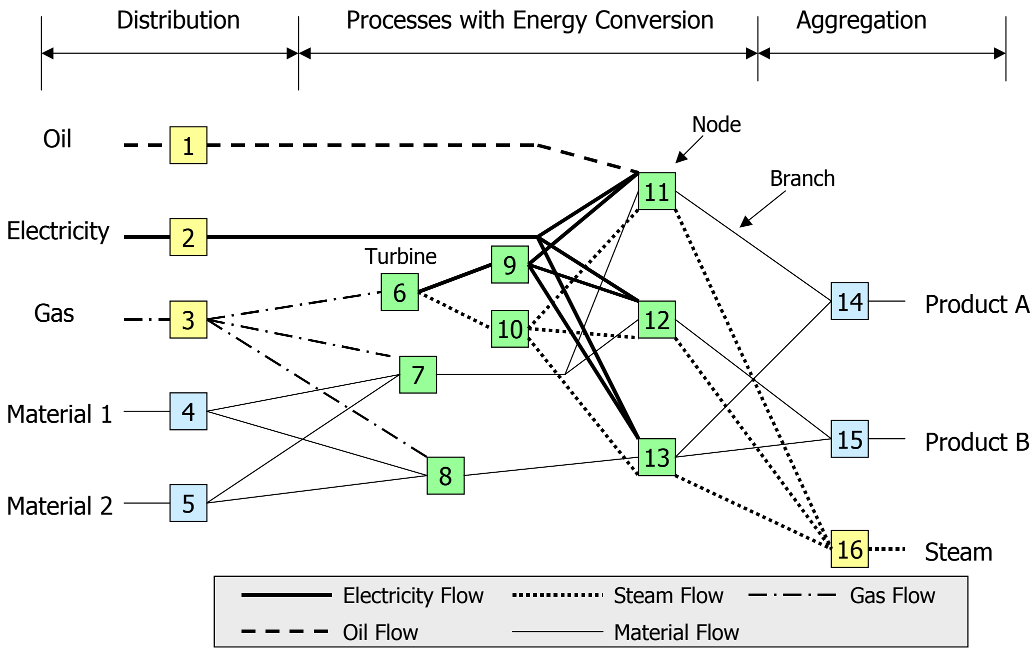

Figure 4. An example of the integrated production and energy system model.

- *Interconnection of Material and Energy Flows*: The material flow of a production process may undergo physical and chemical changes. In the model the material flow of a process node can be altered by a multiplication factor. Flows can also be distributed and aggregated in a percentage relation of the total flow through a node. The energy demand (steam, electricity) of process nodes is represented as a function of the material flow through the node. All process nodes can be specified by the choice of energy demand functions. The energy demand function can be chosen from seven possible functions, shown in Figure 5 below. The energy demand is often non-linear in relation to the material flow through a process. Non-linear relationships are linearised and approximated by step, slope, and break point (BP) parameters. A process node can have more than one energy demand function (e.g. a combination of steam and electricity demand).

- *Energy Recovery*: The recovery of energy (e.g. process heat) can be represented in two different ways. It can either be included as a reduction of the process energy demand, i.e. the recovered heat is consumed within the process, or it can be defined as a function of the material flow, which will result in a usable flow of, for example, hot water or steam, which can be sold or re-used somewhere else in the system.

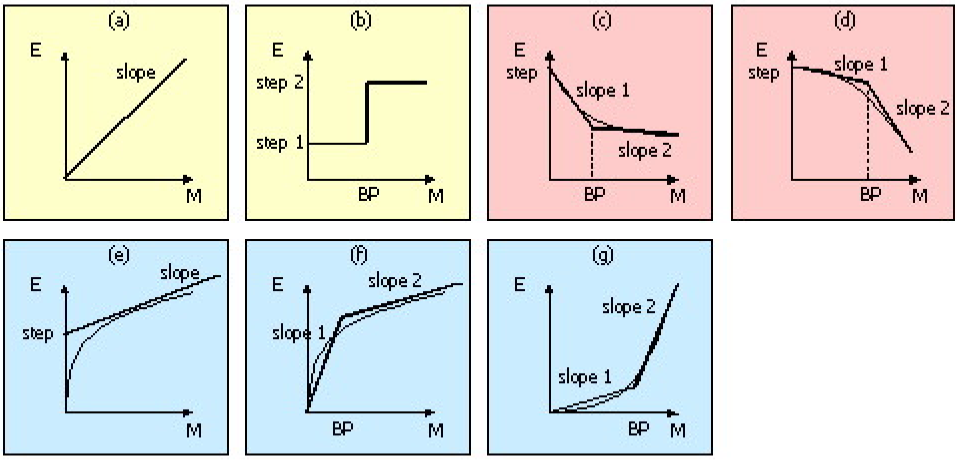

Figure 5. Seven possible energy demand functions "E" as a function of material flow "M" [4].

- *Energy Conversion*: Energy conversion nodes represent the conversion of fuel into steam, electricity into steam, fuel into electricity, or steam into electricity. These conversion functions can either be linear or non-linear, similar to the energy demand functions shown above. An energy conversion factor can be used to represent the conversion efficiency of the one form of energy into the other.

- *Energy Distribution*: In some industrial systems, external steam or heat can be purchased. A distribution node shall represent such facilities. A coefficient for distribution efficiency can be introduced. This coefficient could reflect the difference between the purchased amount of energy and the amount delivered at the point of use in the process system.

4.3.2 System Cost and Objective Function

The optimisation is performed with the objective to find the minimum system cost. This goal includes costs and incomes considered significant for the industrial energy system. The mix of costs may vary from case to case, but costs for energy and raw material are normally included. It is possible to include electricity Maximum Demand (MD) costs in the objective function. The MD charge is only applicable during Peak Demand periods, which vary from tariff to tariff. It is possible to add an income from selling energy in the objective function. Fuel costs are expressed in terms of energy, volume or mass units (e.g. c/kWh, R/litre, R/ton).

4.3.3 Flexible Time Division

Time division shall be made in accordance with known cost changes and the flexibility of the production processes, which include the variation of boundary conditions and internal system changes. Two time scales can be used. One for short-term (hours, days, weeks) and one for long-term (months, seasons, years). The length of a short-term time step can be adjusted for each long-term time step. It is then possible to choose the number of short-term time steps, each with optional length, as well as the number of long-term time steps.

For example, two long-term time steps can be chosen (i.e. Winter season, Summer Season), and within each of these two time steps, three short-term time steps can be defined. (i.e. for the Winter Season, a daily Peak Demand period between 07h00-21h00 on weekdays, a daily Off-peak Demand period between 21h00-07h00 on weekdays, and an Off-Peak Demand weekend day; and for the Summer Season, a daily Peak Demand period between 06h00-22h00 on weekdays, a daily Off-peak Demand period between 22h00-06h00 on weekdays, and an Off-Peak Demand weekend day).

4.3.4 Variable Boundary Conditions

The flexibility of the production level of each process can be defined by bounds for the material flow. An upper bound may represent the maximum capacity, while upper and lower bounds may represent the limits for the flexibility of material flows. Bounds can be given new values for each time step, or a constant value for the whole calculation. Special situations could be included, such as planned production stops (e.g. planned maintenance periods), changes in availability of raw material or fuel, and changes in storage capacity of energy and material.

4.3.5 Choice of Accuracy Level

The representation of process equipment units is performed in a general manner, where all kinds of equipment can be included. Since every node represents different processes in a general way, the method will allow for the presentation of processes at various levels. One node may represent whole process equipment, a part of process equipment, or several aggregated process equipment units. Higher levels of accuracy can be obtained by using more nodes.

For example, if a production plant consists of a number of process equipment units to produce a product, and data or knowledge are available to derive only the total energy demand function of the plant, then this production process will be represented by one process node, at a corresponding low accuracy level. Further where it is not easy to find natural dividing parts in the production system the production system is represented as a single node.

4.4 Optimisation

The first step in the process is for the Knowledge Engineer to build the knowledge base and model. The model will be a graphical representation of the industrial production/energy system, expressed in process nodes and flow lines.

The plant model is linearised as explained above, and a Linear Programming (LP) algorithm is used to obtain optimal values for the model variables, subject to a given set of constraints. If so required, the operator before each optimisation run can adjust the set of constraints. An example would be the real-time determination and adjustment of energy requirements in a process.

The results returned from the LP solver (which is a supporting tool in the IDSS structure) are analysed and evaluated by rules that are captured in the knowledge base by the Knowledge Engineer. The fitness of the optimised production schedules is prompted to the operator, who will be in a position to either accept the proposed schedules for implementation, or to change the input parameters to the LP solver as suggested by the IDSS and run the optimisation again.

Under a dynamic tariff like Real-Time Pricing (RTP) where electrical energy rates vary per hour, this optimisation process will typically be executed once a day when the set of prices for the following day has been received from the supply utility, and also on an hourly basis to take short-term changes in the plant conditions into account.

5. CASE STUDY: THE MANGANESE ALLOY WORKS OF SAMANCOR AT MEYERTON

5.1 Plant Overview

Metalloys, Advalloy, and Dense Media Ferro Silicon operating at the Meyerton Works form, together with the Manganese Mines, the Manganese Division of Samancor in South Africa.

The products produced by Metalloys are silicon-manganese and high carbon ferro-manganese, collectively termed bulk manganese alloys. Currently seven electrical submerged arc furnaces in three different plants (West, South and North) are employed in the process of the production of the manganese alloys. The Advalloy operation produces medium and low carbon FeMn, collectively referred to as refined manganese alloys. The operation of Advalloy is integrated in the West Plant complex with a significant proportion of the current output of the M12 submerged arc furnace at West Plant being dedicated to the production of refined alloys.

Due to the nature of its processes, the plant is a huge consumer of electrical energy, of which 80% is supplied by Eskom. The co-generation plant, utilizing the waste gases from furnaces M10, M11 and M12, supplies the remainder of the electrical energy requirement. In October 2000 Samancor Meyerton converted from the Nightsave tariff to Real-Time Pricing (RTP) for the electricity supply by Eskom. Electrical power levels to the arc furnaces can be reduced substantially for a number of hours without influencing the quality of the output product significantly. With spare production capacity available, the reduced production rate during high RTP hours can be made up during low RTP hours. The possible “swing” in electrical power that is available from the seven furnaces for load control is about 40% of full load capacity.

The co-generation plant has 35% spare capacity as a result of having a larger generator than can be utilized at present making it an ideal candidate for generation using external fuel sources at times of high RTP prices. This can obviously only be cost-effective if the operational cost of the generator, expressed in terms of c/kWh, as a function of the cost of the imported energy is lower than the RTP price, or market price when the market is deregulated, for the time that the external fuel is being imported.

5.2 Integrated Production and Energy Planning at the Samancor Meyerton Works

The integration process is still in the initial phase, where the production system, energy system, production planning and control, etc. are being audited. The flexibility of the controllable processes is large, and the co-generation facility adds another dimension to the flexibility of the whole system for optimisation purposes. This control flexibility, together with the dynamic nature of the electricity rates (RTP as well as the DSM initiative) and the availability of an alternative energy source for cogeneration, makes the opportunities for optimisation and energy cost savings large.

Figure 6 below shows the graphical representation of the plant model as built in G2™, a real-time expert system (knowledge-based system). The vertical flow lines represent the material flow from the input of raw materials at the top, to the dispatch of products at the bottom. The daily production demand for each product is one of the input parameters obtained from the company's production planners. External energy inputs (electricity and gas) are shown at the left hand side of Figure 6.

Under a condition of steady-state operation the furnaces generate an electrical energy demand at a linearised function of the rate of material flow through them. The most suitable of the seven possible energy demand functions displayed in Figure 5 can be selected for each furnace. The three large furnaces (M10, M11 and M12) also produce gas at a function of the furnace load, which in turn is a function of the rate of material flow through them. This gas, together with externally supplied gas at a certain dynamic tariff, is fed to the co-generation plant, which produces electricity at a function of the combined rate of gas flow through it. This electricity is fed back to the furnaces and to the auxiliary load via a distribution node. Eskom supplies the remainder of the electricity requirement at RTP rates.

6. CONCLUSIONS

If the dynamics of an industrial plant can be synchronised with the dynamics of the electricity pricing signals, the customer can expect to achieve a great portion of the potential cost savings that the electricity tariff holds for his business. Customer dynamics include the current state of the plant, production targets, production achieved, maintenance planning, alternative energy sources, benchmark targets, benchmarks up-to-date, labour issues, market conditions, plant & production rules, production constraints, and process constraints.

However, it will be a complicated task for a production planner to take production dynamics into account together with the dynamics of electricity prices in order to determine the best production schedules for the next day that will result in the lowest energy costs, while obeying all plant and process constraints and reaching targets. This makes a decision-support system indispensable.

A concept to integrate energy costs into the production planning process using a decision-support system is proposed in this paper. The objectives and architecture of such a concept are described, and it is shown that an intelligent decision support system will be imperative to implement the concept of integrated production/energy planning. To be able to provide decision support, knowledge of the problem domain is absolutely essential, as well as technology on which to build and implement the knowledge base. Innovative technology is available to implement the proposed functional blocks, and it is the task of Knowledge Engineers to capture domain knowledge during plant audits and to populate the knowledge base.

Such system will be imperative to guide managers and production planners in their hourly to daily managerial and planning tasks to achieve the most from the cost saving potential of the electricity tariff under a dynamic pricing scenario and in a deregulated energy market environment.

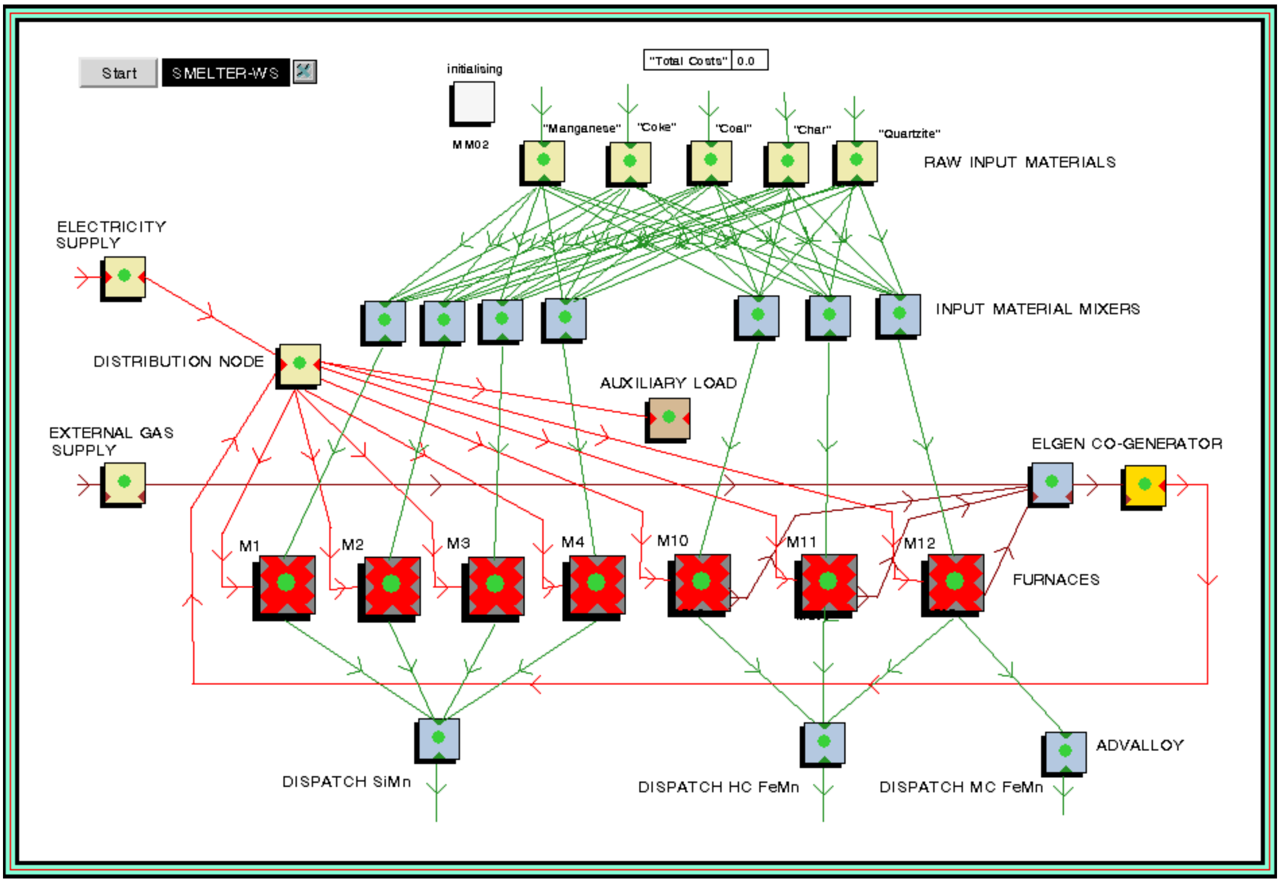

Figure 6. Integrated production and energy model for Samancor Meyerton works.

7. REFERENCES

[1] Roos, M., "Volatile prices on the way for big SA users?", African Energy Journal, Vol. 3, No. 2, March 2001, p. 4.

[2] Eskom Demand-Side Management's Information Guide for Energy Services Companies, Eskom, 2002.

[3] Dhar, V. and Stein, R., "Intelligent Decision Support Methods", Prentice-Hall, New Jersey, 1997.

[4] Nilsson, K., "Cost-effective Industrial Energy Systems – Multi-period Optimisation of Operating Strategies and Structural Choices", Ph.D. Thesis, Department of Mechanical Engineering, University of Linköping, Sweden, 1993.