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Business Process (4IR) Centric Optimization Modelling

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Abstract

Current best practice methodologies of energy utilization are limited to core production processes, excluding non-core processes. Energy determinations are limited to specialized functions and do not cover the entire business. This research introduces business process modelling to evaluate the holistic business energy demand, inclusive of core production and support functions, of a coal fired power plant. The methodology includes, modelling and statistical techniques, in developing the holistic baseline model, with predictive capacities to forecast the energy impact of changes to the business. Post a validation cycle, the results provide for insights on the impact of optimization, including Cleaner Production, IoT and technology substitution on the coal to energy business. The results include CO_2 impact, energy impact and resource (people) impacts as forecast by the model. The model is unique in that it is system agnostic and can be used to forecast any energy production configuration.

Keywords: Energy modelling, energy optimization, Fourth Industrial Revolution, CO_2 emissions

1. Introduction

Despite shifts to renewable technologies and the use of gas for power generation, coal remains a significant fuel source accounting for 36% of global power generation [1]. 60% of the global coal fired power stations are less than 20 years old, with significant remaining lifespan [1]. Further to this an additional 170 GW of coal fired power is under construction globally [2]. This makes improving the efficiency of coal fired power stations a priority [1]. In 2019 the US Department of Energy agreed on funding up to 38 million US dollars towards improvement of the performance of power plants [1]. Existing power plants are accountable for 30% of energy related CO_2 emissions globally [2]; a key

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factor in optimization of coal fired energy generation is global warming i.e. keeping global temperature rise to below 2^oC.

Fourth Industrial Revolution (4IR) technologies present opportunities for power plant optimization. Digitalization in the power sector could result in savings of 80 billion US dollars annually [3]. Digitalization could increase flexibility of power systems and assist in integration of renewable technologies [3]. However, digitalization comes with increased energy usage. Digitalization of energy delivers on optimization and thus improvements in energy efficiency, offsetting this additional usage. Thus, energy efficiency improvements are critical.

Energy modelling is an established method for analyzing and improving performance of energy systems [4 - 5]. The energy system can be analyzed at various resolutions identified including; global, regional, country, local, business, process and equipment. A business is any corporate entity, state owned or private, such as a power utility. Various models exist for each resolution, with the TIMES, POLES, MARKAL and E3ME models widely applied at the global, regional, country and local level. These models evaluate the energy system from fuel extraction to final energy users and are typically classified as bottom-up, top-down or hybrid. The models are complex, time and data intensive and require a high level of expertise [6]. At the process and equipment level there are a number proprietary software such as Aspen Energy Analyser, Arena, Envisage and Sentinet Systems. These models are highly specific, and data intensive (typically requiring quantitative and disaggregated data) [6]. There is a notable gap at the business level, lack of a comprehensive energy model inclusive of all business functions.

This study proposes an alternative approach to energy modelling of a business. Business processes, a recognized business management tool, is applied in developing a comprehensive energy model. The model includes additional functionality of optimization.

2. Literature

A Scopus search is conducted to determine the current status of research in the key areas of the study. The search is conducted with the key search terms, "coal fired power generation AND modelling AND Fourth Industrial Revolution" and its synonyms to capture all relevant publications. The search was constrained to the last 10 years (2010 – 2019) and identified 152 publications. A year on year increase in publications is observed, with the exceptions being 2012, 2015 and 2017, which had a decline from the previous year. In the last three years there has been average 18% increase in publications. China has the highest number of publications at 66, followed by the USA with 31, representing 64% of all publications. The United Kingdom, in third place has 11 publications. China and the USA are the top two coal fired power generating countries, with India in third place [7]. The number of publications from India is low, five publications in the last 10 years, given India's coal fired power generation capacity. A review of the relevant highest cited publications and most recent publications, identifies two recurring themes that are also interrelated:

- Carbon Dioxide Emission Control: Reference [8] evaluates the effectiveness of the 5 US$/t$CO_2$ tax for stationary sources of 50MW or higher in Chile. The model determines that power plants will only consider application of Carbon Capture and Sequestration (CCS) at taxes equal to or greater than 40 US$/t$CO_2$. Reference [9] develops an optimization model to predict low carbon power paths for Shandong Province from 2016 - 2030. Key features of the model include incorporating the elimination of coal power overcapacity and retrofitting existing coal fired power plants with CCS. The analysis of the model results reveals: less than 300 MW units would be eliminated by end of 2021; 1000 MW units would be the primary generation units with only a few retrofitted with CCS; the capacity of clean technologies is not impacted by coal power overcapacity elimination and CCS application; gas-fired, nuclear and solar power have greater potential in Shandong Province [9].
- Modelling/Simulation: Reference [10] conducts a review of dynamic simulation models application in thermal power plants (coal, nuclear, combined cycle and solar). Dynamic simulation is applied in optimization of plant performance and control system and safety analysis. Reference [11] develops a non-linear model for the design of the control system of a once through boiler, with the model parameters based on the operational data of a 1000 MW super critical once through boiler. The model data was compared against measured data and found to be satisfactory.

This paper focuses on the theme of modelling/simulation. An alternative approach to power utility energy modelling and optimization is proposed, which also enables CO_2 emissions and other business performance indicators for modeling and optimization.

3. Methodology

Power utilities generate, transmit and distribute electricity to end users. Each aspect of operation of generation, transmission and distribution has a specific mandate but all are required to operate synchronously, with generation producing electricity, transmission transferring high voltage electricity across vast distances from power stations to various sub-stations and distribution transferring low voltage electricity from the sub-station to end users. A disruption in one operational aspect impacts the continuity and safety of the remaining.

The operation and management of power utilities is multifaceted and challenging. At the highest level a power utility is categorized into functional business units typically comprising; generation, transmission, distribution, Human Resources (HR), Financial Management (FM), Information and Communications Technology (ICT), Research and Development (R&D), Safety, Health, Environmental, Quality and Risk (SHEQR), Customer Services Management (CSM), Integrated Planning(IP), Logistics, and Maintenance. The generation, transmission, and distribution business units are the value chain operations, with the remaining units providing essential support. As the power utility has various operation across multiple sites across thousands of kilometers, quality and consistency of operations across sites is obligatory. Business processes, an established tool for managing and optimizing businesses, is applied in sustaining consistency, quality and transparency of operations. Business processes detail the logical sequence of activities in execution of a business activity [12]; start-up of a boiler, conduction of a steam turbine performance test, performance evaluation of personnel and payment of invoices. Business processes, whilst sequential in nature may have multiple parallel paths, decision blocks based on operational parameters, and cross links with other business processes. Business processes may be common across multiple sites, site specific, equipment specific or process specific.

Business processes are generally aligned to the operational structure of the organization, hence in a power utility business processes are hierarchically structured. Business processes expand in detail and complexity from the business unit level to the activity level. A six level hierarchy is adopted for a power utility:

- Level 0 - Business Unit Level: Is the functional categorization of the power utility, example of generation business unit.
- Level 1 - Process Area: Is a specific area within each business unit level such as boilers in generation.
- Level 2 - Process Function: Is the categorization within each process area, such as boiler operations in the boiler process area.
- Level 3 - Business Process: Details the sequence of tasks for a specific activity, example boiler start-up.
- Level 4 - Business process step: A specific step of the business process. An example based on the boiler start-up business process is; ensure that all inspection openings in the boiler are properly gasketed and closed.
- Level 5 - Activity level: Is a specific task such as, Check that each opening is properly closed and mark on check sheet.

The activity level is explicit enabling quantification of resource requirement such as personnel skill, number of personnel, equipment (from ICT to process equipment), execution time of task and resource utilization time. The specificity of the activity level facilitates quantification of the energy demand, with the simulation of all activity level energy demand culminating in a business energy demand, as represented by Equation 1.

$$\mathit{Business\ Energy\ Demand} = \sum_1^k \sum_1^l \sum_1^m \sum_1^n \mathit{Resource\ Energy\ Demand} * \mathit{Utilisation\ Time} \tag{1}$$

Where
k: number of business sites,

l: number of business processes,
m: number of business process steps and
n: the number of resources

Equation (1) illustrates the application of a simple methodology to quantifying the energy demand of a power utility. The benefits of the proposed approach include:

- Inclusivity of all activities of the power utility from HR, FM and CSM to the process operations of boilers, turbines, and water treatment.
- The facility energy demand of HVAC, lighting and network is evaluated, as each has specific operational and maintenance business processes.
- The comprehensivity of the activity level facilitates evaluation of additional business performance indicators of personnel hours, execution time of activities and CO_2 emissions.

To execute Equation (1) a business process based energy model is developed. In simulation of the energy demand there are two requirements; the business process and the resources. Thus, the building blocks of the energy model are a database of business processes and resources. A third database of optimization is included as following quantification of the energy demand optimisation is expected. The business processes database comprises all business processes applicable to the power utility inclusive of transmission and distribution. The database is structured as per the business process hierarchy detailed earlier. The resources databases is structured on functionality such as ICT (both office and network infrastructure), facilities, and operations (pumps, fans boilers). Within each functional area, the equipment are further classified on equipment design: pumps are categorised as centrifugal or positive displacement pumps; boilers are categorised as sub-critical, critical or super critical. Each equipment has a specific operational regime and energy demand. The optimisation database is dual functional, comprising the optimised business processes (digitalised and automated of processes) and the resources required for execution of the optimised processes. Open source data such as company annual reports and equipment datasheets are utilized in developing the three databases. Applying the three databases, the model methodology is illustrated in Figure 1.

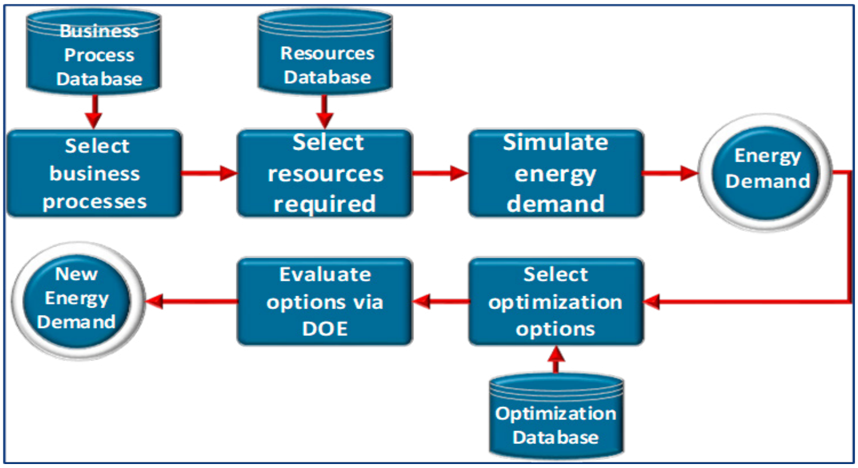

Fig. 1. Energy model framework

In business, the execution path for a business activity is dependent on the business conditions at the specific time, hence business processes have decision blocks. The path followed cannot be accurately predicted given the influence of various factors, both internal and external. To simulate this uncertainty the model applies the Random Function to each decision block, constrained to specific upper and lower bounds. This introduces noise into the model, which is moderated by Monte Carlo Simulations. The Monte Carlo Simulation is run until the change in the standard error of the mean of the energy demand is negligible. This indicates the model has stabilised, representing the utility's baseline energy demand.

4. Results

To demonstrate the methodology, the energy demand of a generation site and a central corporate office inclusive of building facilitates of a power utility is evaluated. In the corporate office the subsequent centralised operations ensue; establishment of power utility Vision and Strategy (V&S), Sales and Marketing (S&M), IP, CSM, ICT, FM, HR and R&D, with some functions also occurring at other sites. At the generation site, the primary objective is production of electricity, henceforth referred to as operations, supported by; planning, maintenance, logistics, ICT, FM, HR and SHEQR. Each of the afore mentioned business units comprise various sets of business processes, each delineated to the activity level.

The generation site evaluated generates 3600 MW of electricity via six 600 MW coal fired boilers, with a coal feed rate of 1800 tons/hr. Due to the proprietary nature of operations, only the steam generation business process from coal delivery to steam turbine is evaluated, as per the business process illustrated in Figure 2. The remaining operations systems of water treatment, generator and transformer are excluded from the evaluation.

The resource requirements of the steam generation business process is extensive ranging from boilers to steam turbines to conveyor systems to pumps to instrumentation, with all resources extracted from the resources database. The generation site has varying operational hours, with some operations and laboratory functions running 24 hours a day and others running eight hours day as with the support functions. The corporate site operates the standard business hours of eight hours per day. Following the methodology illustrated in Figure 1 the energy demand of the corporate and generation site is quantified.

The sites energy demand is a function of the business activities, facilities, and network demand, with the generation site having additional demand of coal and other fuels. The business activities represent all activities executed by the various business units, specific to the site being evaluated. The energy demand of the generation site is categorised as electrical or fuel. Both sites energy demand is evaluated on an annual basis. Figure 3(a) illustrates the generation sites electrical demand, with p indicating the primary y-axis and s the secondary y-axis. The business activities is the largest consumer of electrical energy, followed by facilities and network. The business activities energy demand is the largest as it includes the operations electrical energy demand. The coal demand represents 99% of total fuel demand, being the primary fuel source. Other fuel sources such as diesel, and fuel oil account for the remaining 1% of fuel demand. At the corporate site the key consumer of energy is the facilities (HVAC and lighting), followed by network and business activities, refer to Figure 3(b). Figure 3(a) and 3(b) further illustrate the immense difference in energy demand between the two sites, with the generation site energy intensive.

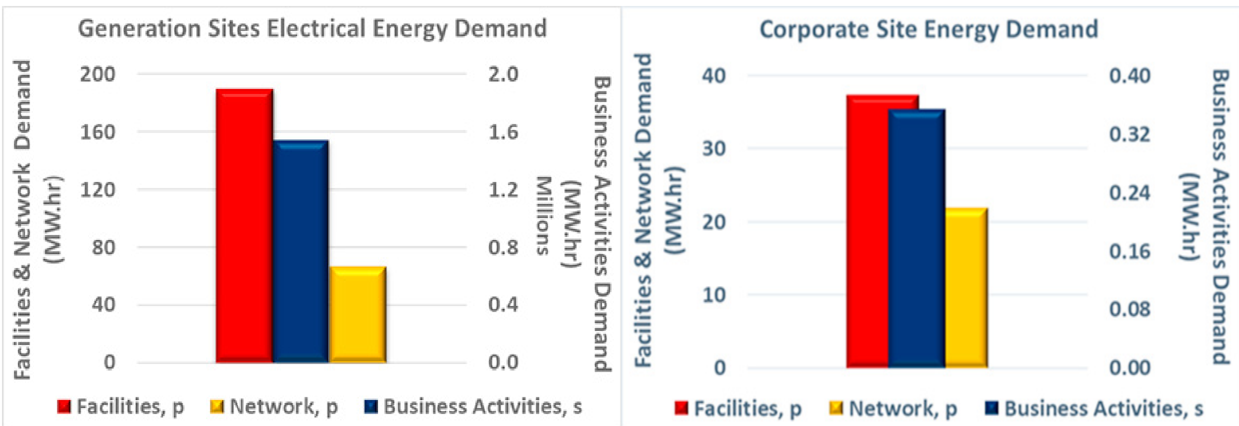

Fig. 3. (a) Generation site electrical energy demand; (b) Corporate site electrical energy demand

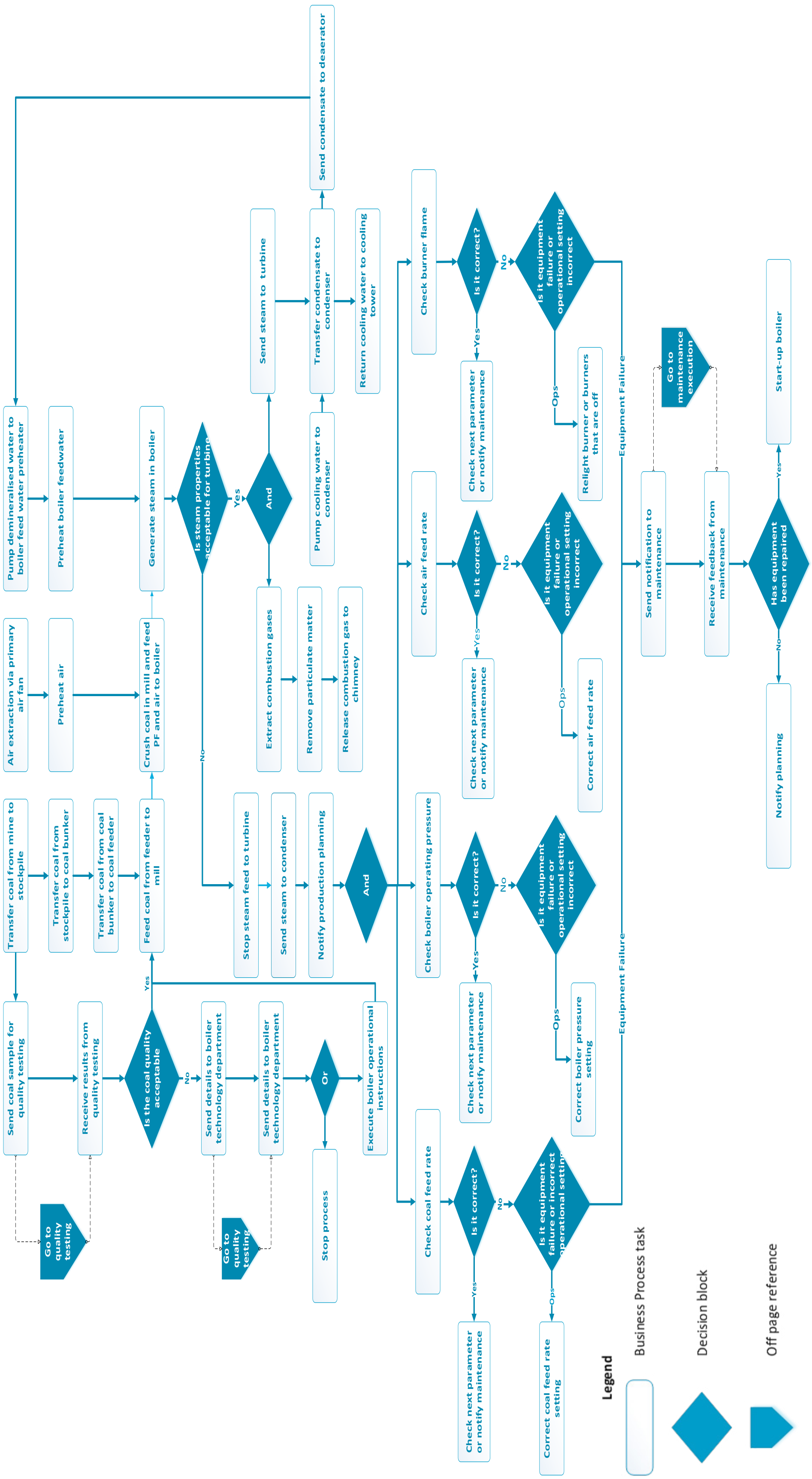

Fig. 2. Coal preparation to steam production business process for coal fired power generation

As the model adopts a bottom-up approach, the results are available at various resolutions; site level, business unit level, and equipment level. Figure 4(a) illustrates the energy demand at the business unit level for the generation site, excluding operations. The SHEQR business has the highest energy demand, followed by financial management and logistics among the support functions. These business units have voluminous repetitive tasks; coal quality testing, payment of invoices and salaries. The operations business unit is excluded, as the required energy demand is magnitudes larger; energy demand of the operations business unit is 1,541,588 MW.hr per annum.

The lowest resolution is the equipment level. Figure 4(b) illustrates the demand of the energy intensive equipment of the steam generation process. The primary air fan and the boiler feed water pumps have the highest intensity, due to the high volume of air being drawn in for combustion and high steam requirements.

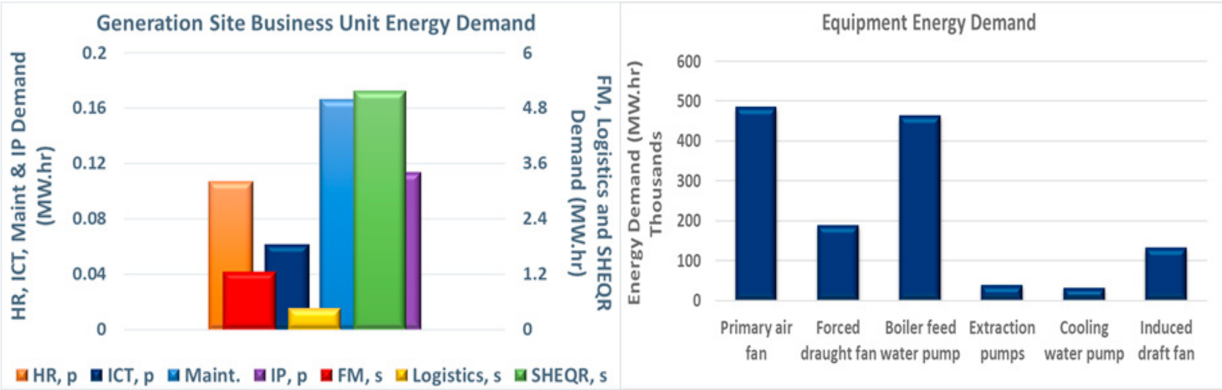

Fig. 4. (a) Generation site business unit energy demand; (b) Energy demand of operational equipment

The business unit energy demand of the corporate site is illustrated in Figure 5. The highest energy consumers are customer service management, followed by vision and strategy (there is continuous review across the structures of the business) and sales and marketing.

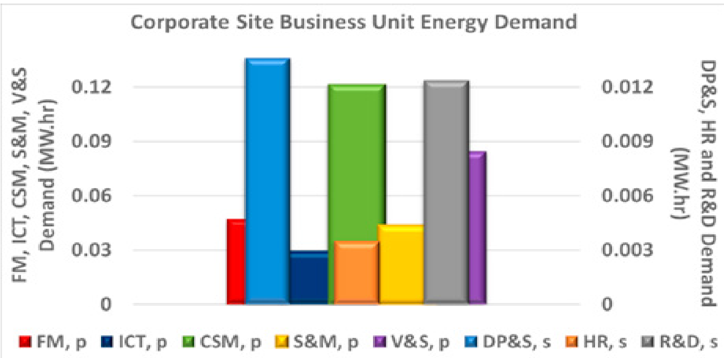

Fig. 5. Corporate site business unit energy demand

Figures 3 to 5 demonstrate the energy model's capability in evaluating the energy demand of the generation and corporate sites site from the site level down to equipment level. The model identifies the generation site has the higher energy consumer of the two, with the operations business unit being the most energy intensive.

5. Optimization of Energy Demand

The identification of the operations business unit as highly energy intensive provides a focus area for optimization. The value adds of adoption of Industry 4.0 and Cleaner Production technologies in energy management is documented [13 - 14] , hence are selected for optimization. With the identification of the electric motors of the various fans and pumps as the largest contributor to the energy demand of the steam generation process, Variable Frequency Drive (VFD) is selected. VFD adjusts the motor speed for the available flow, thus the motors are not operating at constant speed continually, typically set close to the maximum flow.

A review of the business processes of the operations business unit identifies Industry 4.0 technologies of Internet of Things (IoT), Big Data Analytics (BDA), mobility and automation for application in the business processes of Production Tracking, Review Operations Performance and the cross-linked business process of Out of Specification Coal (SHEQR business unit).

- Automation: Use of software to transform captured data to required format for various analyses: evaluation against key performance indicators; determination of process efficiency, emissions rate and, steam throughput and automatic generation of reports. Work analysis tool for streamlining and prioritization.
- IoT: Capturing of real-time equipment and process performance data for analysis, with the information transferred to the equipment for self-adjustment in real-time.
- Mobility: IoT enables mobility, allowing personnel to work while being away from site.
- BDA: Sophisticated analysis of data for predictive purposes; maintenance intervals, optimum operational regimes.

A number of options are available for application, but given the financial, and resource constraints of a power utility it is not feasible to apply all. A structured analysis is required to determine the most suitable optimization option for adoption. The energy model utilizes the Design of Experiment (DOE) methodology to evaluate the potential options singularly and in combination to identify the best option and mix of options.

The model combines mobility with IoT, resulting in four optimization options; VFD, automation, IoT and BDA. Applying the DOE methodology, 16 optimization options are evaluated. The coal energy demand is excluded from the analysis, with the focus on electrical energy demand to demonstrate model capacities.

VFD demonstrates the highest impact in reduction of energy demand, a reduction of 22%, refer to Figure 6. IoT singularly reduces energy demand by 5%, whilst automation reduces demand by 3%. IoT assists in integrating the various aspects of a system, resulting in wider area of impact. The adoption of all optimization options results in a 28% reduction in energy demand. The reduction in energy demand has multiple benefits; reduction in energy costs and in Green House Gas (GHG) emissions.

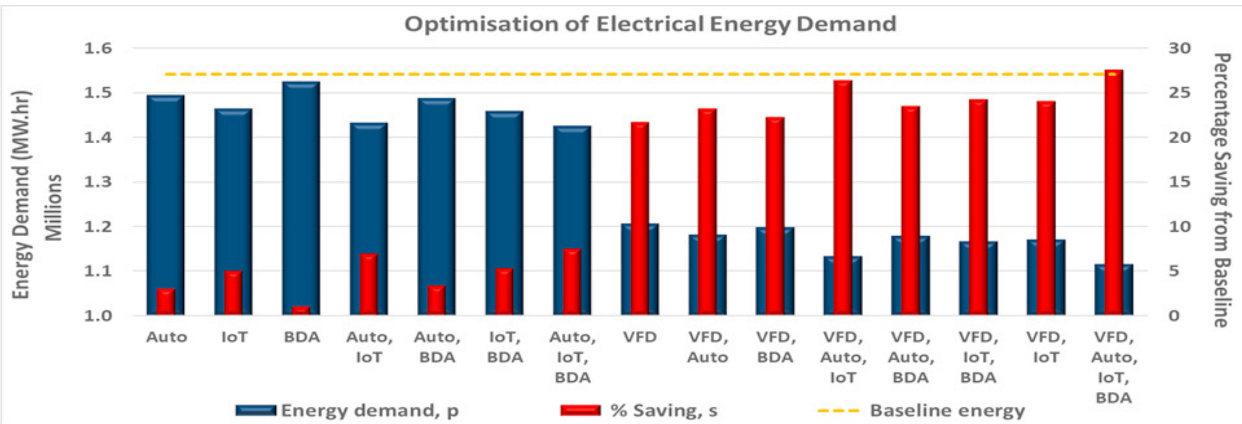

Fig. 6. Impact of optimization options on generation site electrical demand

The impact of VFD on the energy intensive equipment of the steam generation process is illustrated in Figure 7. It results in an approximate 25% reduction in energy demand.

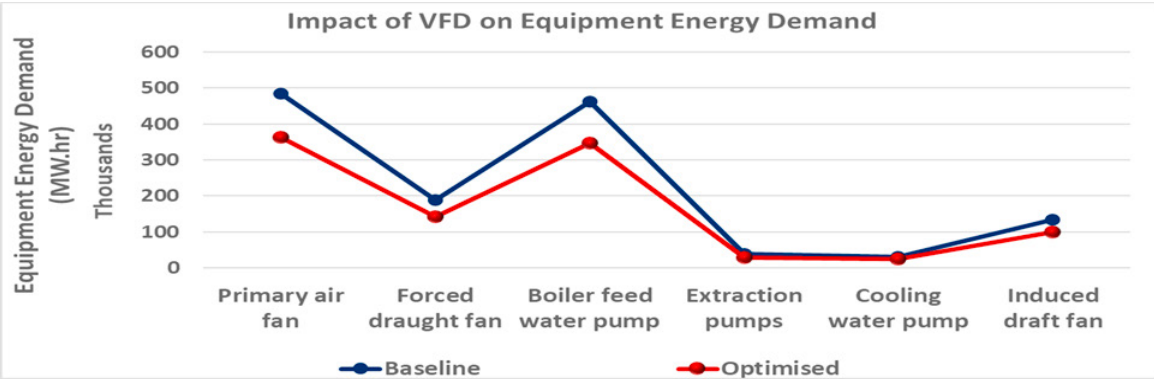

Fig. 7. Impact of VFD on steam generation equipment

The use of business processes also enables evaluation of other business performance indicators such as carbon dioxide (CO_2) emissions and personnel hours' requirement, as illustrated in Figure 8. Figure 8 demonstrates the model capacities in evaluating alternate business performance indicators and proves the model concept. The model is in the initial stages of development and subject to further improvements.

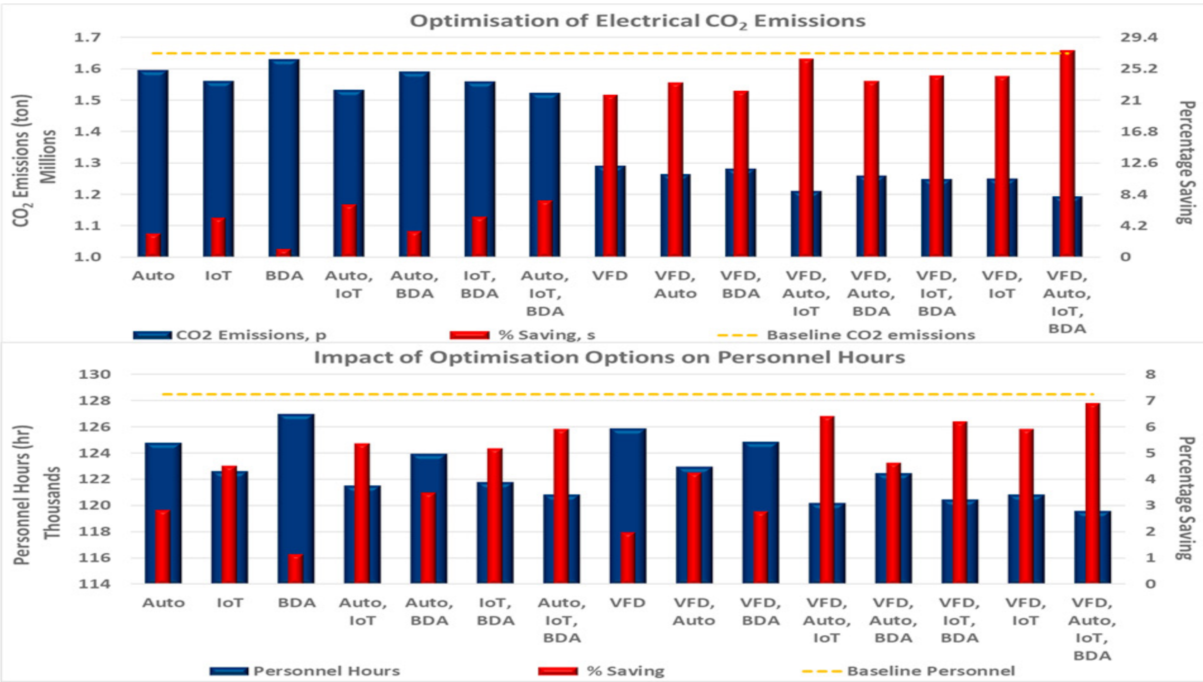

Fig. 8. Impact of optimization options on generation site annual CO_2 emissions and personnel hours

The model provides the utility with critical information (specific to its equipment and operational regime) to aid in energy optimization investments. The results demonstrate that application of VFD has the highest impact on reduction of energy demand, and is potentially the best investment, followed by IoT. The application of IoT would be a key step towards digitalization of operations.

6. Conclusion

The challenge of conducting a supplier agnostic, holistic energy evaluation of an energy production business is addressed in this research paper. The approach is to convert the activity of the business into business processes. The processes include various business functions inclusive of Human Resources, Financial Management, Information and Communications Technology, Research and Development, Safety, Health, Environmental, Quality and Risk, Customer Services Management, Integrated Planning, Logistics, and Maintenance. Business processes are successfully mapped, modeled and variables adjusted to predict baseline energy demand. The research adopts modeling, and statistical techniques to develop the business process centric model. The model has the additional capacity, to be adopted, to predict future energy demand. The model predictability is based on optimization of operations including technology, IoT and Cleaner technologies.

The model proves capable and advantageous in predicting various components of the coal fired power plant. The calculated business impacts on energy, CO_2, and people are illustrated. The potential of the business process approach is proven with further research to be conducted to advance the business process modelling capability.

Acknowledgements

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