Eskom

Eskom Power Plant Engineering Institute

EPPEI

2020 Programme

Eskom Academy of Learning

Driving towards Engineering Excellence

Contents

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Foreword

Welcome to another edition of the EPPEI Programme Book.

As we all know, Eskom is currently navigating a very difficult terrain filled with predicaments and there is more lying ahead.. In order to meet and overcome these challenges, Eskom Guardians need to be adequately capacitated so that they can adapt to the changing energy landscape, by acquiring relevant specialized technical skills and competencies through the EPPEI programme. With the acquired skills and competencies the Eskom workforce will be better equipped to bring about the change required to turn around the organisation's technical performance in the specific critical areas.

The Eskom Power Plant Engineering institute (EPPEI) is a partnership that was established in 2012 between Eskom and academia, to improve the technical skills and knowledge of the electric power industry and, more specifically, Eskom's workforce. Close collaboration between industry and universities, including universities of technology, through specialisation centres in EPPEI has brought about significant benefit to the organisation since research and study towards postgraduate qualifications focus on Eskom-specific technical challenges.

Over the past year, significant work was undertaken to define the DNA of operating, maintenance and engineering practitioners and developing a skills matrix that can be used to identify skills and competency gaps. The EPPEI team has made good progress to partner with academia across the spectrum, to develop the desired level of training courses that will support the development of engineering practitioners from a foundation to an advanced specialisation level.

In the second phase of EPPEI I am pleased to report that a total of 131 specialists and experts have graduated to date, with research masters' or doctoral degrees in various technical fields. Of the 131, 29 graduated with PhDs and 72 with masters. 72 of these students were Eskom employees. Currently we have 155 students enrolled in the EPPEI programme, seventy from Eskom, all of whom are working closely with Eskom industrial mentors and academic supervisors on Eskom-specific technical challenges.

Great effort has been put into collaborative engagement with all Eskom stakeholders and the EPPEI scope of work is now guided by various technical forums with representation from Research Testing & Development (RT&D), engineering centres of excellence, Steering Committee Of Technology (SCOT) Study Committees and caregroups, the three new divisions (Generation, Transmission and Distribution).

An EPPEI collaboration site was implemented internally to Eskom, to provide improved communication and sharing of the EPPEI Programme outputs.

In this Programme Book you will read about the new students who joined the EPPEI programme and their projects. We look forward to their graduation as well as the outcome of the operational and applied research that will be implemented in the organisation.

Happy reading.

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EPPEI Programme Director

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4 EPPEI Specialisation Centre academic representatives

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5 Asset Management Report & Completed project summaries

Since the inception of the EPPEI programme in 2012 a total of 38 masters degree research projects lead by the University of Pretoria and Tshwane University of Technology, have been completed by the Asset Management Specialisation Centre. During the early years, most of the attention was focused around problems related to the structural integrity of Eskom physical assets such as steam turbines.

A large number of student research projects were focused on resolving problems related to various aspects of steam turbine structural integrity. These projects included the development of probabilistic methods to account for uncertainties in material properties, damping, stress cycle histories, in the prediction of Eskom steam turbine blade fatigue life. Another example of the early work was the development of practical finite element modelling approaches to understand the torsional behaviour of turbo-generator trains. The focus of this research gradually converged towards the development of techniques which can be used to infer the levels of steam turbine blade vibration from measurements of the blade tip time of arrival at a particular point on a turbine casing. These techniques are commonly known as blade tip timing techniques.

This research lead to the development of a number of novel concepts which could be applied to conduct practical online condition monitoring of turbine blade vibration. Because of the potential impact of using such techniques for optimised operation of turbines that have exceeded design life, Eskom RT&D subsequently initiated a large project to implement these techniques for rotating blade health monitoring. This is a multiyear project which is led by Eskom RT&D in association with the centre at the University of Pretoria. Current EPPEI research aims to take these concepts even further and focus on prediction of blade remaining useful life, i.e. extending the diagnostic capability that was developed to a prognostic capability.

Since 2015 the range of activities of the specialisation centre expanded considerably with a much broader focus on asset life cycle management. An interesting example of this work is a project which developed novel techniques to measure maintenance productivity at Eskom. By applying rigorous statistical tests to empirical data from Eskom, the validity of measuring maintenance productivity as a strategic performance indicator was established and a relationship was found between strategy and productivity. It was shown that the relative ease of measurement and broad application of these metrics could be exploited by senior management engaged with strategic decisions.

Recently, Risk Based Inspection (RBI) became a very important focus area in the centre, as a a preventive maintenance strategy that combines prediction of the expected failure time based on statistical methods, with condition monitoring to prevent potential equipment failures. Various RBI implementation studies have been conducted at Eskom to investigate the efficiency and effectiveness of RBI implementation, and it is believed that this will have significant impact in Eskom in the future.

In another recent project a framework for the assessment of asset operational readiness (AOR) for new build power plant was proposed. The study developed AOR assessment tools, qualitative survey tools and scoring systems. It is anticipated that this will enable stage wise assessment of each component for individualized performance rating.

Duvha Power Station EPPEI 100 Day Challenge Project

Prof Johann Wannenburg | Chair: Eskom Power Plant Engineering Institute
Centre of Asset Integrity Management | Mechanical & Aeronautical Engineering | University of Pretoria

EPPEI, is driving towards significantly upskilling of engineering practitioners through industry-focused research, post-graduate qualification and training programmes. However, training, innovation and leadership development are necessary but not sufficient to produce different results. Research and upskilling timescales are typically measured in years, whereas the need for improved performance is immediate. EPPEI has considering ways of accelerating its impact.

A medium term impact proposal is embodied in the EPPEI Task Force initiative, where the Specialisation Centres would assess potential improvement areas at the operations, prioritise and address through assignments (short to medium term projects where site personnel are assisted/coached/trained to support delivery of results).

What about short term impact? It is known that people can achieve extraordinary results when confronted by burning platforms, as was powerfully demonstrated by South Africans when preparing for the 2010 Soccer World Cup. In recognition of this concept, the US-based Rapid Results Institute (RRI) has developed a methodology based on energising organisations through waves of 100-day challenge-driven projects.

An approach, Rapid Results 100-Day challenges, was introduced to Eskom, as an alternative way to leverage the strengths of technical and engineering skills and capabilities within Eskom and in within our education institutions and it was proposed to test this approach through a pilot project at Duvha power station.

The premise of the approach:

- Duvha personnel have a good grip on Priority Improvement Projects (through the work with consultants and currently managed through their "Incubator", lead by Mr Mehendra Maharaj.
- Duvha personnel have sufficient internal knowledge and capacity to solve their problems.
- Duvha can benefit from a structured approach which would assist with accelerating execution of tasks related to these improvement projects, aimed at energising and mobilising cross-functional, supervisor/operator/artisan level teams, leading and executing 100 Day Challenge projects.

During sessions with the Duvha General Manager, Mr Mandla Mthembu and his senior leadership team, five projects where prioritised and team members identified and invited to participate in the launch workshop on 9-10 March 2020.

Duvha 100 Days Challenge Summary Sheet

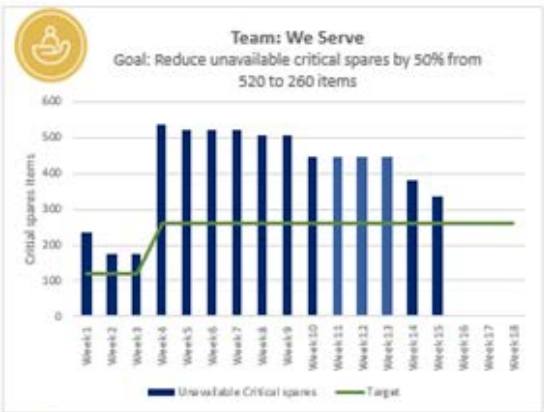
Project	Goal	Team Leaders	Sponsor & Co-sponsor	Googles	Project Focus
1. Procurement Process	Reduction of 1000 PR's in 100 days	Jerry, Tebogo and Louis	Neo Mkhize & Ollof Nel	Antonie Mammes	• Review PO placement duration • Technical requirements • Small Companies • Cross functional teams • Human resources • Systems (IT, SAP) • Eskom subsidiaries and sole source
2. Mills Availability	To reduce the current 40MW UCLF to 15MW UCLF (from 1.3% to 0.5%)	Simphiwe & Zama	Morris Marebane & Mzwakhe Simelane	Lettie Botha	• Mill Exspress • Preventive and Corrective Maintenance • Coal Quality • Mill Dampers • Seal Air Fans • Quality Control
3. Outage Performance	Unit 2 RTS 3 days ahead of schedule	Thandeka & Bulelani	Muzi Myeza & Preetha Sewlall	Thabiso Moirapula	• Resource Support • Quality Control • Spares Management • Maintenance Defects and Postmortem • Scope Creep • Water management for unit RTS • Safety Performance
4. Spares Availability	To reduce unavailable critical spares by 50% (from 135 to 65 items)	Kwenda & Refilwe	Kakanyo Mabaso & Msebenzi Khanyile	Joey Nkgapele	• Expediting • Stock Taking • Lead Times • Technical Criteria
5. Oil Burner Reliability	All 24 burners per running unit tested and available by 10 a.m. daily	E. Moosa & D. Child	Nielen Toerien & Dumisani Thabang	Ivan Hartman	• PM Compliance & Function Testing • Human Resources • Results logging • Maintenance Strategy • Fuel Oil Plant (North & South)

Over the past 4 months, progress on these already challenging projects had been hampered by the additional complexity caused by the Covert-19 virus pandemic, resulting in an extension of the duration. However, during the latest weekly dashboard reports from the teams, all five of the teams seem set to be able to achieve their very ambitious targets at the end of the project, which is testimony to the extraordinary efforts from the teams.

It also demonstrates the validity of the expectation that this approach, compared to conventional interventions, would have the following benefits:

- The projects are practice fields for transferring ability to operational personnel to support results acceleration and culture change, achieving a just-in-time pull for expertise, coaching and training from sources outside of the operation (eg from universities), rather than the same being push upon a dispirited and unconfident workforce.
- The approach encourages experimentation, learning and adjusting, trusting that the right strategies will emerge through action and experimentation.
- Through action, rapid results are achieved, energising and motivating the workforce, enhancing ownership and buy-in from operational personnel.
- 100-Day Challenges strengthen relationships between people who do not usually sit around the same table.

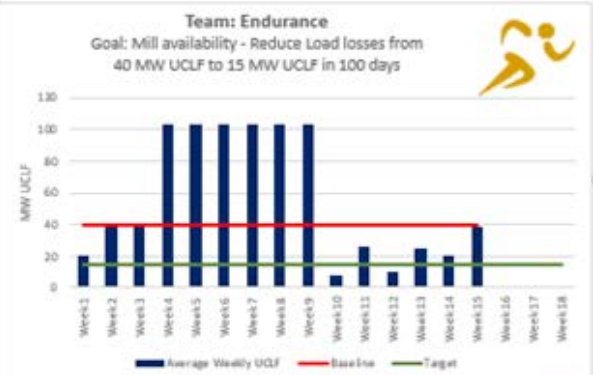
The methodology is highly scalable, with deliberate internal capacity building in the methodology being the next step after completion of the pilot project. It is hoped that more of these projects would achieve a rapid spread of the good news and results and decreasing needs for outside facilitation.

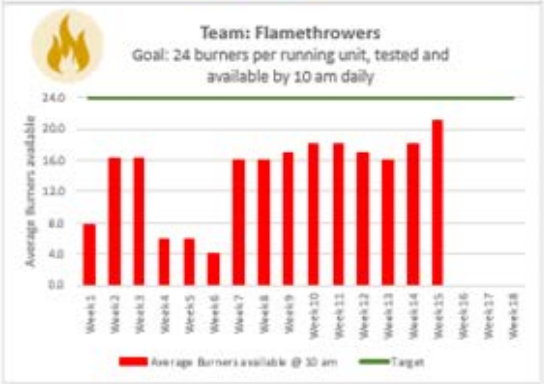


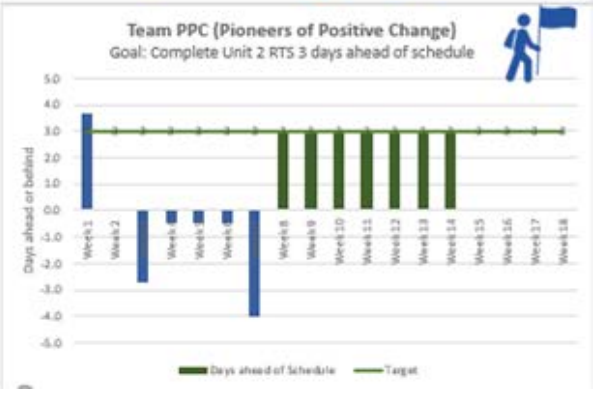
Eskom

Duvha RRI 100 Day Challenge

01 July
Day 79
of 100 Days







Asset Management: Completed Project

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A real-time hybrid method based on blade tip timing for diagnostics and prognostics of cracks in turbomachine rotor blades

Project summary:

The purpose of the study is to propose hybrid models for (i) diagnosis and (ii) remaining useful life estimation of a single fatigue crack in a low-pressure turbine blade. The recommended hybrid methods consist of physics-based methods and data-driven methods.

Project detail:

Blade tip timing is used to measure the relative tip displacement of a rotor blade. The natural frequency of the blade is determined by detecting the critical speeds of the blade using a newly derived least squares spectral analysis method. The method shares its origin from the LombScargle periodogram and can detect resonance frequencies in the blade's displacement while the rotor is in operation. A Campbell diagram is then used to convert the critical speed into a natural frequency. Two kinds of shaft transients are considered, a run-up run-down crossing the same critical speed, is used to test the new method.

This dissertation shows that the relative displacement of the blade tip is comparable to those simulated from an analytical single degree of freedom model. It is also shown that the newly proposed resonance detection method estimates the natural frequency of the blade to a high degree of accuracy when compared to the measurements from a modal impact hammer test. A Gaussian Process Regression model is trained on data collected during experiments and finite element simulations of a fatigue crack in the blade.

Benefit to Eskom:

The purpose of the research is to establish how the vibration-based condition monitoring can be used to predict failure in turbomachine blades while the blades are in operation. This can help to reduce maintenance costs by repairing or replacing components that require it; contrary to replacing components that could remain in operation for much longer than initially estimated.

Greg Janse Van Vuuren (MEng)
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Extracting blade condition information from the pressure field around a turbine blade

Project summary:

Turbine stages are exposed to a variety of excitation sources in the power industry. This study is centered on investigating blade vibration and its relationship with the flow field through a steam turbine which is largely applicable to the power industry.

Project detail:

The resulting forced vibration excitation of the blades may occur near a blade's natural frequency. Blade vibration is an inevitable, inherent characteristic of turbines as the rotor blades travel through the trailing wakes of the upstream stator blades. Blade vibration can be worsened by other mechanisms such as pitting, corrosion fatigue and stress corrosion cracking commonly experienced in the power industry.

Measuring turbine blade vibration allows for condition monitoring of the blades for damage. This is often coupled with finite element models of the blades or with computational fluid dynamic models of the flow field around the blades. These numerical methods, although well-established, lack the complexity of the true multi-physics phenomena within a turbine. As the blade vibration measurement techniques essentially capture blade vibration that is the result of fluid-structure interaction (FSI), blade vibration should be modelled as a coupled problem, but this is usually computationally expensive. A rudimentary yet fundamental numerical model of a turbine stage is thus required to model the fluid structure interaction while minimising computational costs and retaining accuracy.

Benefit to Eskom:

The project proposes ways of evaluating which parameters can assist in monitoring turbomachinery blade condition in practice.

Asset Management: Completed Project

Dominic Kafka (PhD)

Automated learning rates in machine learning for dynamic mini-batch sub-sampled losses

Project summary:

Learning rate schedule parameters remain some of the most sensitive hyperparameters in machine learning, as well as being challenging to resolve, in particular when mini-batch subsampling is considered. Therefore, this study aims to specifically distinguish between static and dynamic mini-batch sub-sampled (MBSS) loss functions.

Project detail:

Mini-batch sub-sampling (MBSS) can be conducted in a number of ways, each with their own implications on the smoothness and continuity of the underlying loss function. In this study, dynamic MBSS, often applied in approximate optimization, is considered for neural network training. For dynamic MBSS, the mini-batch is updated for every function and gradient evaluation of the loss and gradient functions. The implication is that the sampling error between mini-batches changes abruptly, resulting in non-smooth and discontinuous loss functions.

This study proposes an approach to automatically resolve learning rates for dynamic MBSS loss functions using gradient-only line searches (GOLS) over fifteen orders of magnitude. A systematic study is performed, which investigates the characteristics and the influence of training algorithms, neural network architectures and activation functions on the ability of GOLS to resolve learning rates. GOLS are shown to compare favourably against the state-ofthe-art probabilistic line search for dynamic MBSS loss functions. Matlab and PyTorch 1.0 implementations of GOLS are available for both practical training of neural networks as well as a research tool to investigate dynamic MBSS loss functions.

Benefit to Eskom:

The project suggests techniques to eliminate the need to tune the most expensive hyperparameter, namely learning rates, for neural networks used in process predictions.

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Preventative maintenance optimisation in a capital-constrained environment

Project summary:

Historically, preventive maintenance was regarded as a secondary business process that adds additional, albeit necessary, costs to production activities. This study research aims to develop an overall preventative maintenance optimisation methodology concerning a budget for a specific plant that can be used in a decision process for an organisation.

Project detail:

Historically, preventive maintenance was regarded as a secondary business process that adds additional, albeit necessary, costs to production activities. Recently this perception has changed, and more time and effort have been directed into attempts to optimise maintenance strategies within the context of sustainably achieving the business goals of organisations. Due to the recognition of the importance of maintenance from an organisational perspective, a number of different maintenance-related approaches have been developed. These approaches include reliability centered maintenance, business-centered maintenance, total productive maintenance and life cycle costing. Common to all these approaches are techniques to optimise the maintenance strategies using mathematical models.

The study focuses on data-driven optimisation models that consider costs and the reliability performance of equipment. The practical implementation of these optimising maintenance models presents two main challenges. Different models based on analysing the historical failure data of the system or component are considered in order to optimise the maintenance strategies to be applied to these two types of individual systems. A major limitation of these maintenance optimisation models is that they all require failure data for their implementation, which is not always obtainable.

Benefit to Eskom:

This study presents an integrated maintenance optimisation model that uses the appropriate sub-models described individually in the literature to enable the integrated compilation and sound presentation of an overall maintenance budget for a complex plant for appropriate decision-making.

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Informative frequency band selection for performing envelope analysis under fluctuating operating conditions in the presence of strong noise and deterministic components

Project summary:

Under varying speed and load conditions it is difficult to isolate bearing damage. Therefore, this research is aimed at identifying features of a vibration signal that are robust against varying speed and load.

Project detail:

Effective incipient fault detection requires a method that can separate fault signatures under constant and time-varying operating conditions. Identification and optimal selection of the informative frequency band which contains fault information is the focus area of the research in this article. Many automatic band selection techniques exist and have proven effective under constant speed and load conditions. However, it has been shown that these techniques occasionally identify frequency bands that contain non-damage related information, especially under fluctuating operating conditions and at low damage levels.

With this research, a new methodology is proposed which makes use of popular informative frequency band selection techniques, such as the Fast Kurtogram amongst others, to effectively identify damage under constant and fluctuating speed and load conditions.

A key step in this methodology, the NICogram, requires healthy historical data, which is used to identify frequency bands that contain novel information in unclassified signals. The methodology uses multiple signals to identify whether a component is damaged or not through a probabilistic approach. It is shown that the method performs much better than the conventional informative frequency band identification methods on synthetic and experimental data.

Benefit to Eskom:

The NIC Methodology provides real time analysis of equipment condition and has the ability of advanced warning of machine failures and so allows for unexpected breakdowns to be minimized improving equipment availability. The benefits include increased asset life, reduced overall maintenance costs and an increase in maintenance planning and efficiency.

Bernard van der Westhuizen (MEng)
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Impact of coal quality on equipment lifetime at coal-fired power stations

Project summary:

While the impact lower quality coal has on cycle efficiency is understood, the influence it has on equipment reliability and lifetime is often not understood. The present study aims to investigate the impact of varying and deteriorating coal quality on the life-time and reliability of equipment in coal power stations.

Project detail:

The influence of coal calorific value and ash content has on air-heater element erosion was evaluated. This was accomplished by establishing a correlation between calorific value and ash content of coal from a specific colliery; this was then used to calculate the mass of fly ash and flue gas produced when burning enough coal to satisfy the boiler load. An erosion model was then used along with historical coal quality and air heater erosion history to develop and fit a model for full boiler load.

The model was verified against data not used during the development of the model, and a seemingly good prediction was made when compared to the measured result. The calorific value of the coal in the model was varied for a hypothetical situation; this indicated that as calorific value decreases the erosion of air heater elements increases. The influence abrasiveness index has on mill liners was also investigated as part of this study. Historical liner ultrasonic thickness and coal abrasiveness index results were used to fit a mathematical formula.

Benefit to Eskom:

The impact lower quality coal has on cycle efficiency is understood, the influence it has on equipment reliability and lifetime is often not understood. This project adopts a holistic approach, while considering the impact of variation of various coal characteristics, including thermal and mechanical characteristics on various critical equipment in a coal power station production chain, in terms of various degradation mechanisms.

6 Emissions Control Report & Completed project summaries

The EPPEI Specialisation Centre (SC) for Emissions Control was established to assist Eskom in meeting the current and future environmental regulations with respect to particulate and gaseous emissions. To this end, the SC is involved in the quantification of pollutant emissions from Eskom power plants, the assessment of the impacts of the emissions on human health and the environment, and research and development on the technologies used to reduce these emissions to regulatory acceptable levels.

In terms of emissions quantification and the impact thereof the EC SC has worked closely with Eskom over the past years to establish a sound scientific understanding of the aforementioned. Through a series of activities that have included dispersion modelling, emissions calculations, emissions measurement, and field observations of ambient and indoor air quality and advanced source apportionment studies, the contribution of power station emissions on the Highveld have been quantified. Impacts from other important sources, especially the emissions resulting from the domestic burning of solid fuel in dense low-income settlements have also been quantified.

Currently Eskom is not able to meet all the Minimum Emissions Standards, and in addition to research on improving the emissions abatement units, emissions offset alternatives have also been investigated and interventions proposed through high quality observations and modelling. The EC SC has been actively pursuing research on one such offset intervention, namely the development of cost-effective, thermally efficient dwellings that can replace the current informal dwellings. Additionally, a novel low-emissions, semi-continuous coal stove that can be integrated into the thermally efficient dwellings has also been designed and is currently being tested. Apart from the abovementioned activities, the EC SC has also worked on modelling the distribution of mercury emissions from power stations and assessed the relative effectiveness of abatement technologies on these emissions.

In terms of research on emissions abatement technologies, the SC has developed a detailed, 3-D numerical model of the Kusile wet flue gas desulphurisation (WFGD) absorber. The model was validated using plant data provided by Steinmüller Engineering GmbH. The validated model can be used by the process engineers to simulate a range of plant conditions, which can greatly assist in process optimisation, troubleshooting, and diagnostic testing. The EC SC has also developed a process model for reducing WFGD water consumption through flue gas heat recovery, and in collaboration with Steinmüller Engineering GmbH., the model was validated against their proprietary WFGD Design Program. Using the model, water savings of roughly 30 % is predicted to be possible with the implementation of different flue gas heat recovery options. Such water savings would make WFGD water consumption comparable to that of conventional semi-dry FGD systems, which is also being studied within the SC. For example, the SC has also rendered support to Eskom on the design of the riser of a circulating fluidised bed (CFB) absorber of a pilot-scale semi-dry FGD system. The SC has also established world-class laboratory facilities that includes a resistivity measurement apparatus to characterise fly ash resistivity, which is a key factor that determines electrostatic precipitator (ESP) performance. Other laboratory facilities include a laboratory-scale ESP, fabric filter plant (FFP), and semi-dry flue gas desulphurisation (FGD) units, i.e. a laboratory-scale spray dry scrubber and circulating fluidised bed (CFB) riser. Apart from being used in research, the equipment can also be used for demonstration and training purposes.

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A computational model for the description of electrostatic precipitator performance

Project summary:

A composite computational model that can account for the interacting fields of fluid dynamics, particle dynamics and electrostatics was developed along with experimental validation using ESP experimental setup.

Project detail:

The In the developed computational model, electrostatic equations were solved using OpenFOAM while particle charging and particle dynamics equations were solved using STAR-CCM+. The Euler-Lagrange approach was used to model the respective gas and particle flow, and turbulence were taken into account using the k-epsilon turbulence model.

The developed computational model was intermittently validated with experimental results available in literature in terms of the electrostatics properties as well as particle collection efficiency. The model was subsequently further refined and validated with experimental and computational results taken from the literature to study the shielding effect that can arise in the case of multi-electrode ESP systems.

The developed computational model was finally validated with experimental results obtained using an in-house laboratory-scale ESP. The use of both wire-electrodes and spiked electrodes were studied, and the modeled and experimentally measured V-I relationships and particle collection efficiencies were compared under shielding and non-shielding conditions. Good agreement was achieved between the measured and modeled V-I relationships of the wire-electrodes, both under shielding and non-shielding conditions.

Benefit to Eskom:

A representative computational model of and ESP can be used to enhance existing ESP performance through ESP modification, find optimum operational parameters and identify efficient process control strategies.

Konstanze-Marie Bosman (MSc)
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Modelling source contributions to ambient particulate matter in Kwadela, Mpumalanga

Project summary:

This study forms part of an intensive air quality sampling campaign conducted in Kwadela, a small low-income settlement between Bethal and Ermelo, Mpumalanga. The aim of this campaign is to quantify the baseline air quality during summer and winter in a typical poor, domestic fuel burning community.

Project detail:

The overall aim of this study was to evaluate how to use a steady state Gaussian dispersion model to simulate urban ambient air quality for regulatory purposes in the South African context by modelling source contributions in a small community.

Benefit to Eskom:

Emissions dispersion models have various limitations. Some of these limitations are addressed in the study and so offers a cost effective method to evaluate the impact of ongoing and future offset projects on air quality.

Jeanne Fourie (MEng)
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A cost-benefit analysis of the inclusion of polyimide in fabric filter bags

Project summary:

An evaluation of the techno-economic considerations for the incorporation of polyimide (PI) in polyacrylonitrile (PAN) and polyphenylene sulphide (PPS) based fabric filter bags for the control of particulate emissions from coal fired power production.

Project detail:

The study investigated the comparative fabric chemical compatibility with acidic flue gas constituents as well as the electrostatic properties of the various polymeric fabrics. A model was developed which incorporates the chemical and electrostatic parameters into a cost-benefit analysis tool for use in making bag selection decisions for optimal filter bag cost and performance.

Benefit to Eskom:

An analysis of cost benefit versus performance trade-off is used in optimizing bag filter selection criteria. The study furthermore contributes towards the optimization and performance of currently installed and planned Fabric Filter Plants.

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Process integration in coal fired stations

Project summary:

The primary objective of this study was to determine the reduction of the raw water intake of an existing power station by applying process integration techniques to optimise the use of water available in the system

Project detail:

The primary objective of this study was to determine the reduction of the raw water intake of an existing power station by applying process integration techniques to optimise the use of water available in the system. The secondary objective was to reduce the waste water produced within the process, hence reducing the cost of water, reducing the amount of chemicals and reducing the energy needed to treat water.

Process integration as technique for water minimization was initiated by identifying the water sources (providers) and sinks (users) in the water network, thereafter matching appropriate sources and sinks as water quality allows.

Based on preliminary runs of the model, three role players in the Kriel water utilisation network were identified:

- Wastewater treatment plant water re-use
- The possibility of blow down water re-use due to different water chemistry in the respective cooling towers
- The ability to use any water to wash floors
- Three different objective functions were set for each of these scenarios and the objective functions to be minimized were:
- Freshwater intake into the station
- The sum of freshwater intake and wastewater produced
- Cost associated with water intake and waste handling

Benefit to Eskom:

This study focuses on minimizing fresh water intake and at the same time limit the amount of waste water produced. It also looks at reducing chemicals used for water treatment and ultimately reduce costs of water accounts.

Jandri Ribberink (MEng)
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The influence of moisture on resistivity of selected South African fly ashes

Project summary:
The study focussed on fly ash resistivity, an ash characteristic that commonly influences ESP performance. Three ashes from the Eskom fleet were collected, characterized and their respective resistivity vales determined over a range of temperatures.

Project detail:
One of the key parameters significantly affecting the collection efficiency of electrostatic precipitators is the electrical resistivity of the fly ash. Resistivity is an intrinsic, physical material property denoting the ability of a material to oppose the flow of electrons.

The electrical resistivity of fly ash is influenced by a number of key factors most notably the ash mineralogy and the flue gas conditions. A flue gas parameter that strongly influences fly ash resistivity is the relative humidity of the gas stream. The moisture present in the gas stream allows for the formation of a very thin water layer on the surface of the fly ash facilitating the transfer of electrons.

The experimental setup used in this study was a resistivity oven, previously utilized by Eskom RT&D, recommissioned and updated to include SO_3 conditioning and humidification. The resistivity data obtained from the resistivity oven indicated the dependency of resistivity on humidity. For example, fly ash from a reference power station showed a 86% reduction in the resistivity value when comparing a dry sample to a humidified sample (6.2 vol% H_2O) at the average ESP operating temperature (±150°C). With resistivity showing a strong dependency on humidity, three ash samples from the Eskom fleet were characterized and the resistivity values obtained at various moisture levels and temperatures. The given data was used to develop a simplified statistical model to relate fly ash resistivity, humidity and fly ash mineralogy at various temperatures.

Benefit to Eskom:
A lower fly-ash resistivity is generally associated with improvement of ESP performance. Effective use of moisture to lower ash resistivity can propose steam / water as a low cost alternative to SO3 flue gas conditioning.

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The reactivity of South African limestone of variable quality as potential sorbents in wet flue gas desulphurisation

Project summary:

Limestone is used within the Wet Flue Gas Desulphurisation process (WFGD). The cost of limestone is dependent on the distance that it has to be transported. This study investigated the use of different quality limestone sources and determining the applicability of using lower quality sources, which in some cases are located closer to the power stations, for their respective use in the WFGD process.

Project detail:

The reactivity of the investigated limestone samples, did not correlate with the rate of dissolution. It is was concluded that factors such as particle surface area, porosity, degree of crystallinity, and the presence of the dolomite mineral and other impurities have a significant effect on the dissolution.

It was found that the modified first-order semi batch model developed through this study, gave an accurate representation of the experimental data, from which total reaction rate constants could be derived.

If only the rate constant was to be considered, the lowest quality limestone investigated, would be suitable as a sorbent in the WFGD process. However, an investigation into the impact of other aspects of operation would have to be considered.

It was recommended that optimization the WFGD should be done in each case where a limestone from a different source is utilized, as the dissolution rate of each limestone source had different correlation with regards to varied experimental conditions.

Benefit to Eskom:

The optimisation of water and sorbent resources on the FGD plant process, assist in mitigating the risk of resource availability and reducing associated waste management, thereby managing the environmental footprint of the station. If lower quality limestone sources are found to be viable in the use of FGD, it will have an economic impact which could benefit Eskom.

Hendrik Willem van Riel (MSc)
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Evaluation of fabric filter plant operating costs as a function of bag filter dimensions

Project summary:

An analysis on three different bag filter diameters was conducted as a function of cost and differential pressure. Operating and capital cost are the key elements that needed to be considered during the evaluations.

Project detail:

After taking the various bag dimensions, and by applying the same scenarios to all with regards to differential pressure, ash cake build-up and pulsing pressure a conclusion could be made that: The larger diameter filter bag has proven to be the most cost-effective bag when comparing operating and capital costs of the life of a plant. There is however a limit to the maximum the filter bag diameter can go to still clean and operate the plant within its parameters.

Benefit to Eskom:

The relevancy of this study to Eskom is in the reduction of operational costs with respect to bag filter usage in existing FFPs, retrofitting ESPs into FFPs and in new built FFPs.

7 Energy Efficiency Report & Completed project summaries

Rising energy demand and the imminent threat of climate change are critical issues in society. Many energy conversion processes are a result of thermofluid systems to provide electricity, heating and cooling. The EPPEI Specialisation Centre in Energy Efficiency (EE) have expertise in modelling these systems. Such models can be used to improve the efficiency of existing plant and enable condition-based maintenance.

Models are built using tools available in industry. Tools such as CFD, the one-dimensional network approach or a combination thereof are used for modelling thermofluid systems. Cutting edge advanced analytics techniques such as machine learning and AI are used for data driven model order reduction. The combination of these capabilities enables the development of accurate and computationally inexpensive numerical tools applicable to industry needs. This work supports the recommendation by Professor Tshilidzi Marwala who urged South Africa not just to be users but also be builders of 4IR technologies. EE have been actively developing skills in this area. Results of these projects were presented to the Generation Process Engineering Steering Committee (GPESC). Implementation is supported by Pravin Moodley, Yashveer Maharajh and Alton Marx from Generation Asset Management.

EE started a partnership with Vaal University of Technology (VUT) in 2017. Ms Lethu Vilakazi is a full-time employee at VUT and enrolled for master's on a part-time basis in January 2017 under Professors Alfayo Alugongo and Pieter Rousseau. Her project enabled her to gain exposure to the power industry through her project which required her to perform an uncertainty analysis on measurements taken at Lethabo Power Station. She was guided by Charlene Govinden who mentored Lethu and enabled access to plant data for model validation. Lethu has enrolled for a PhD at UJ and participating in OMEP training through the foundation physics course.

In 2018 a project was initiated to investigate how the configuring burner swirl can improve heat uptake in the furnace at Lethabo Power Station. Several follow up investigations have been conducted at Lethabo, specifically the investigation of the impact of low load operation on radiant superheaters. This work is now being applied to other boilers in Eskom through task force projects supporting the modelling group within Generation Asset Management.

A master's project by Preetha Sewlall (Senior Engineer – Duvha Power Station) has been shown to be important for Eskom's water management. The approach adopted in this thesis was to learn from the existing Eskom Excel water management tools and develop a standard mathematical model that could be structured in EtaPRO calculation templates. These templates were to be structured such that they function as process components to develop water balances at a power station. It was concluded that it is possible to develop process models within the EtaPRO software from well-defined mathematical models to address the performance monitoring concerns on water systems within Eskom. The methodology is currently being rolled out within Eskom on EtaPro. These projects would have normally been conducted by external consultants. The research-based training approach has enabled Eskom engineers to lead strategic projects in Eskom. EE continue to support Eskom through participation in the GPESC, Boiler Process Care Group as well as the Process Engineering and Energy Efficiency Care Group.

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Low load operation of boiler feed pump turbines

Project summary:
The one-dimensional network approach was used to model the BFPT in an Eskom plant. This model can be used to study flexible operation of coal fired power plants.

Project detail:
The boiler feed pump turbine (BFPT) system of an Eskom unit was modelled in Flownex. The model included individual pump stages, steam admission valves and a stage-by-stage turbine model utilising custom stage components. These turbine stage components represent each stage with nozzles and other standard Flownex components. The boundary conditions of the system were set as functions of generator load in order to represent typical values for use in case studies. The relationships between load and boundary conditions were based on large samples of data from the station's data capture system.

A corresponding standby electric feed pump system was also modelled in Flownex for a comparative case study. After model validation, a number of case studies were performed, demonstrating the functionality of the model and also providing specific results of value to the station in question. These results include the minimum generator load possible with different steam supplies; maximum condenser back pressure before plant availability is affected; the viability of changing the pump leak-off philosophy; and the effect of electric feed pump use on power consumption. Several recommendations for effective operation of BFPTs were made specifically for low load operation.

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A methodology for integrated thermofluid modelling of radiant superheaters in steady state and transient operations

Project summary:

The one-dimensional network approach was used to model the radiant superheaters in a coal fired boiler. Such models can be used for studying transient operation of boilers.

Project detail:

A methodology was developed to model radiant superheater heat exchangers in steady state and transient operations. The methodology is based on a network approach which entails solving the transient one-dimensional forms of the conservation equations for mass, energy and momentum. The model building blocks account for the convective thermal resistance on the steam side, the conductive thermal resistances of the tube wall and scaling or fouling on the tube walls, as well as the convective and radiative thermal resistances and direct radiation on the flue gas side. The ability of the model to analyse the effect of ramp rate during load changes on the tube metal temperature was demonstrated, as well as the ability to determine the maldistribution of flow and temperature on the steam and flue gas sides.

The model was applied to demonstrate the impact of different operational conditions on the tube metal temperatures. Such integrated process models can be employed to study complex thermofluid process phenomena that may occur during intermittent, transient and low load operation of power plants. In addition, such models could be useful for predictive and preventative maintenance as well as online condition monitoring.

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Development of a test rig for testing fouling in feedwater heaters

Project summary:
A test rig was built to study the fouling factors on heat exchanger tubes. The rig is now an available tool for Eskom to use for determining the actual fouling factors for heat exchangers.

Project detail:
Feed water heaters suffer from fouling. In the design of heat exchangers, fouling is accommodated by adding additional surface area to the heat exchanger. The amount of additional area is determined by the use of fouling factors. Although this is the only wide-spread method accepted in industry, the fouling factors in use are outdated, generally considered conservative and lead to oversized heat exchangers. The purpose of this study was to design and build a test rig that can accurately measure fouling factors of feed water heater tubes that has been in service for a full life cycle.

The results indicated that the average measured fouling factors were less than 20% of the commonly used HEI fouling factors. This is significantly lower and confirms that the fouling factors in use for this specific case are conservative. The test rig proved to be accurate and effective in measuring the fouling factors. Although the tests show promising results, the small amount of tubes tested from only one heat exchanger are not sufficient to make meaningful conclusions. The test rig is now ready for a future study where a large sample of tubes can be tested.

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Quantifying the impact of plant anomalies on the ID Fan

Project summary:
A modelling methodology was developed to study the impact of plant anomalies on the ID fa availability.

Project detail:
The focus of this study was to develop and demonstrate a modelling methodology to quantify the effects of major plant anomalies on the capacity of ID fans in coal fired power plants. The ensuing model calculates the operating point of the ID fan that is a result of anomalies experienced elsewhere in the plant. This model can be applied in conjunction with performance test data as part of a root cause analysis procedure.

A one-dimensional network model was used to study the flue gas path. Virtual Plant was used to model the steam cycle and the boiler mass and energy balance was used to model combustion. The integrated modelling methodology was applied to a 600 MW class coal fired power plant to investigate the impact of six major anomalies that are typically encountered. These are: changes in coal quality; increased boiler flue gas exit temperatures; air ingress into the boiler; air heater in-leakage to the flue gas stream; feed water heaters out-of-service; and condenser backpressure degradation.

It was inter alia found that a low calorific value (CV) coal of 14 MJ/kg compared to a typical 17 MJ/kg reduced the fan's capacity by 2.1 %. Also, having both HP FWH out of service decreased the fan's capacity by 16.2 %

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Advanced analytics for process analysis of turbine plant and components

Project summary:
This study assessed the methodology of using machine learning and AI to predict plant performance while comparing to a first principle thermofluid model and actual plant behavior.

Project detail:
A feed forward neural network was used to successfully predict plant behavior under various operating regimes for which it was trained. The limitation of this model is that it is unable to predict behavior under operating modes for which it was not trained. The model could not extrapolate even when alternate activation functions and regularization techniques were employed to improve the generalization of the machine learning model.

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Determining appropriate loss coefficients for use in the nozzle-model of a stage-by-stage turbine model

Project summary:

This project advanced a previously developed one dimensional modelling methodology for steam turbines. The project advanced previous work through the incorporation of blade geometry and loss coefficients for improved accuracy.

Project detail:

A previously developed turbine modelling methodology produced a customizable turbine stage component. Derived from the synthesis of classical turbine and nozzle theory enabled the component to accurately model a turbine stage. Utilizing Flownex the turbine stage component can be expanded to model any arrangement and category of turbine. This project focused on incorporating turbine blade passage geometrical information, as it relates to the turbine specific loss coefficients, into the turbine stage component to allow for the development of turbine models capable of predicting turbine performance for various structural changes, anomalies and operating conditions.

The development of turbine loss coefficient algorithms as they relate to specific blade geometry data clusters required the investigation of several turbine loss calculation methodologies. A stage-by-stage turbine nozzle-model incorporating turbine loss coefficient algorithms was developed and validated against real turbine test cases obtained from literature. Several turbine models were developed using the loss coefficient governed turbine stage component illustrating its array of capabilities. The incorporation of the turbine loss coefficient algorithms clearly illustrates the correlation between turbine performance deviations and changes in specific blade geometry data clusters.

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Online boiler convective heat exchanger monitoring: A comparison of soft sensing and data-driven approaches

Project summary:
An online monitoring tool was developed using existing measurements on a coal fired power plant. This tool was applied to monitoring condition of boiler heat exchangers.

Project detail:
Online monitoring supports plant reliability and performance management by providing real time information about the condition of equipment. However, the intricate geometries and harsh operating environment of coal fired power plant boilers inhibit the ability to do online measurements of all process related variables. A low-cost alternative lies in the possibility of using knowledge about boiler operation to extract information about its condition from standard online process measurements.

This approach is evaluated with the aim of enhancing online condition monitoring of a boiler's convective pass heat exchanger network by respectively using a soft sensor and a data-driven method. The soft sensor approach is based on a one-dimensional thermofluid process model which takes measurements as inputs and calculates unmeasured variables as outputs.

The model is calibrated based on design information. The data-driven method is one developed specifically in this study to identify unique fault signatures in measurement data to detect and quantify changes in unmeasured variables. The fault signatures are initially constructed using the calibrated one-dimensional thermofluid process model. The benefits and limitations of these methods are compared at the hand of a case study boiler.

8 High Voltage DC Report & Completed project summaries

Line design – The research in this area included high temperature conductors, vibration and stranding. At present the Lines course is being developed which will update the previous work and enable engineers in Eskom to be trained in the latest techniques. This enables the use of new high temperature conductor types to be considered and optimisation techniques to be employed. Savings in R'm can be maintained with improved techniques.

Insulator enhancement – Graphene, a 2D nanomaterial, has been successfully produced for the improvement of next generation epoxy insulators and coatings exhibiting hydrophobic, electrical and thermal properties. Application research, testing and production are next steps.

Smart Technologies – This enables the reduction of SAIDI in distribution networks by using smart devices. The research enables the deployment and evaluation of various devices that can be used on the network. The skills developed enable a better understanding of the nature of SAIDI as well as how certain smart devices can be used to improve the overall SAIDI value.

HVDC research – The advent of inverter based resources such as wind farms increase the use of VSC's and HVDC systems. The research in this area enables better understanding of the effect of these devices on the system. This knowledge is critical to the operation of the network as well as protection of the network. SMES and superconducting devices – the application of the DSMES allows for modelling and understanding of the application of dip mitigation on the distribution networks. The development of a superconducting reactor allows for understanding of the modular development of a reactor which is far smaller and depicts low to zero losses on the distribution system. Skills developed cover the nature and application of superconductors which can be used to benefit the grid into the future.

Application of DG and EV on the grid – The research undertaken in this regard is critical to understand the implication of distributed generation as well as the advent of electric vehicles on the grid. The skills and modelling developed assists planners in analysing the network and application of DG and EV.

Efficient lighting impact – The modelling and harmonic pollution of efficient lighting is necessary to understand the effect of these devices on the network. Certain faults due to these effects need to understood and modelled.

Natural ester oils for transformers – There are a great number of benefits from using ester oils. They are less flammable and developed from renewable crops and not fossil fuels. The application and testing as well as impact on transformer design is necessary to understand prior to implementation of this oil and development of standards.

Lightning performance on high voltage networks – The understanding of reduced footing resistance on lightning performance is critical in line and substation design. Skills developed in the modelling and design of earth mats and tower footing is critical in compiling standards and guidelines for implementation.

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Improvement of voltage and dynamic performance of transmission power networks using distributed superconducting magnetic energy storage systems (D-SMES)

Project summary:

Distributed Superconducting Magnetic Energy Storage (D-SMES) is used in this project to demonstrate it's capabilities to mitigate voltage stability in electric power systems.

Project detail:

Over the past 30 years, a device known as Distributed Superconducting Magnetic Energy Storage (D-SMES) has been under development and proposed to solve various grid performance challenges. The use of a D-SMES is considered as a new option at experimental stages to solve plenty of transmission, generation, and distribution system problems, including improvement of voltage and angular stability, increasing power transfer capability, damping oscillation including smart grid. The purpose of this project was to demonstrate how D-SMES can alleviate voltage instability in a network.

The study gives an overview of the D-SMES applications, its characteristics and classification. Two case studies, namely; an IEEE network and a real Southern Africa network are studied with voltage instability under contingency condition. The process flow is proposed and presented using modal analysis as a tool to identify the optimal location in a network to mitigate voltage instability. The results of the two case studies demonstrated improvement in the voltage instability of the respective networks. Modal analysis proved to be an effective method to identify the optimal location of a SMES to improve voltage stability in Eskom networks.

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Analysis of optimal PV penetration levels with time-variant loads in power distribution networks

Project summary:

This study proposes the use of time variant load models in PV penetration studies and compares the penetration levels attainable with them to those attainable with conventional fixed load models. It primarily focuses on the effect the time variant nature of demand has on distribution network voltage levels and assesses the implications of using fixed load models on active power curtailment and energy storage system sizing.

Project detail:

The study uses actual network measured data and SANS 507:1:2007 to develop a time-variant load model for a 315kVA distribution transformer. An equivalent fixed load model based on a few assumptions derived from the transformer loading guidelines of IEC 60354, was developed. Using the voltage standards of IEEE 1547, the PV penetration limits of the 315kVA network with each load model were determined, with no mitigation techniques employed.

An assessment was conducted to determine the loss in PV-generation using curtailment as the sole mitigation strategy and the implications the results would have on energy storage sizing in the network. The results show that the nature of the time-variant load produces several penetration limits, which, unlike the fixed load penetration limit, are not only dependent on injected PV generation but also load demand dependent. A practical implementation using a 1.5kVA PV system connected to a mini-grid with a variable resistive load verified the simulation results.

The technical, metering, and tariff structure for the grid integration of small-scale LV network PV systems are still in development. In order for Eskom to keep abreast of these developments, simulation studies play a crucial role. This study highlights a key simulation study aspect that requires consideration in this standard development process.

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Breakdown of multiple parallel air gaps

Project summary:

Investigation of the effect of the multiple parallel air gaps have on the insulation breakdown strength in medium voltage networks. These are mainly found in complex network configurations such as section links transformer links etc.

Project detail:

The research intended to identify weak points of distribution networks and assess their performance against lightning voltages, which is crucial to ESKOM. Three experiments were conducted in the high voltage laboratory to test some of the configurations commonly used on MV Networks.

Each piece of equipment exhibited higher CFO when tested individually compared to when it is in a configuration under negative impulse voltage. Different configurations have different significances in the distribution system, but they also pose a threat of reducing the performance of the networks against negative impulse lightning overvoltages. Up to 12.38% reduction in CFO was observed in the tested configurations. The percentage reduction of the CFO increase in the configuration complexity.

An increase in the CFO of the configuration is observed when subjected to positive impulse stress. In rare cases, a slight decrease of less than 1.00% in the CFO was observed. This has the potential of decreasing the number of outages caused by positive lightning overvoltages since positive surges are common than negative surges. Up to 26.28% increase in the CFO was observed in the tested configurations.

9 Renewable Energy Report & Completed project summaries

The EPPEI Specialisation Centre for Renewable Energy (SC-RE) at Stellenbosch University was established in 2012, and has since been key to establishing Stellenbosch as the foremost university in South Africa in the area of renewable energy and power system research, education and training.

During the first phase of EPPEI up to end 2016, the SC-RE focussed on renewable technologies like wind generation and concentrating solar power (CSP), aimed at supporting the Eskom Sere wind farm and the World Bank loan CSP plant that Eskom was planning at that stage.

By the time that phase II of EPPEI commenced in 2017, renewables on the Eskom grid were increasing significantly leading to multiple integration challenges. The SC-RE's focus therefore shifted to supporting Eskom in these challenges, with our focus shifting from renewable technologies towards the field of power system simulations and studies.

Within this field, several contributions deserve to be highlighted:

Mitigating the impacts of photo-voltaic (PV) generation on distribution grids
A study in partnership with Eskom, City of Cape Town and UCT quantified the impacts of small-scale embedded generation (SSEG), specifically PV, on distribution feeders and transformers. The study and continuing related research activity inform pro-active grid-interface standards and SSEG hosting capacity regulations like NRS097-2. As SSEG continues to increase in future, such standards and regulations will mitigate costly impacts including premature transformer failures, and feeder and transformer upgrades due to SSEG. Avoided costs to Eskom due to this SC-RE contribution represents percentages points of future transformer failure replacement and distribution upgrade costs.

Improved system operator forecasting accuracy based on South African conditions
The share of variable renewable energy generators like wind and solar in the South African power system is increasing fast. Accurate operational timeframe forecasting is critical to ensure continued system reliability and least cost generation. SC-RE's work in forecasting high speed wind cut-out events and in classifying wind power variability according to atmospheric states has the potential to significantly improve the quality of forecasts available to the Eskom system operator. This in turn will reduce the allocation and use of operating reserves. Avoided costs to Eskom due to increase forecasting accuracy can represents several percentage points of future ancillary services costs.

Adapting Eskom's business model to the renewable energy-based utility death spiral threat
Increasing erosion of utility revenue due to residential and commercial embedded generation (EG) has been termed the "utility death spiral", and is a threat faced by utilities world-wide, including Eskom. Research, models and tools developed by SC-RE, in partnership with Eskom RT&D, quantify the potential future uptake of EG in South Africa as well as the potential financial impact on Eskom, and continues to inform a pro-active Eskom response to the utility death spiral threat. Through this work the SC-RE directly contributes to the future sustainability of Eskom's business model.

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Extending the herman-beta transform for probabilistic load flow analysis of radial feeders

Project summary:

The project involved extending the application of the Herman-Beta algorithm (HBA) LV planning tool to MV and HV systems. The new method, termed the Herman-Beta Extended (HBE), has wide applications, including assessment of the impacts of embedded generation on LV, MV, and HV distribution networks.

Project detail:

The Herman-Beta algorithm (HBA) is the current prescribed method for the design of LV feeders in South Africa, enforced through the NRS34/SANS507 standards. The technique, however, has inherent assumptions that limit its application to selected LV feeders with purely resistive conductors and unity power factor loads. To extend its application, the HBA required a complete reformulation. This research involved the development of a new probabilistic load flow approach for the design and planning of radial distribution networks. The novel formulation termed the Herman-Beta Extended (HBE) remains based on the beta probability density function as a universal descriptor of inputs and the method of moments for the computation of the output PDFs. However, the novel formulation of the transform now considers complex-type input parameters to accommodate loads at various power factors and feeders with significant reactance and susceptance.

Further, the effects of dependency between loads and generators are incorporated directly using covariances. The resultant approach opens many possibilities for new applications, including the accurate analysis of the design of distribution feeders at any voltage (LV, MV and HV), compensated feeders (shunt reactors and shunt capacitors), and systems with voltage-dependent load or DG.

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Optimising power system frequency stability using virtual inertia from inverter-based renewable energy generation

Project summary:

Increasing the stability of the power system frequency using optimal placement of virtual inertia from RES power plants.

Project detail:

Wind and solar power generation, which uses inverters to interface with the power system network does not provide inertial response, thus these generation sources have a detrimental effect on the frequency stability. Inverter-based renewable energy generation are integrated into power systems at an increasing rate, thus, the system frequency becomes more sensitive to disturbances on the network. The result is increased RoCoF, lower frequency nadir and increased difficulty to stabilize the system frequency.

This research focuses on the transient stability of the power system frequency considering large-scale integration of inverter-based generation. The Western Transmission network of the Eskom power system was used as case-study for the implementation of virtual inertia. The H2-norm metric was used to evaluate power system frequency stability. The metric follows from Lyapunov theory for analyzing non-linear system stability through energy functions. The distribution of virtual inertia in the network is optimized using the Genetic Algorithm to minimize the H2-norm. The results show significant performance improvement in frequency transient stability. This indicates that the distributed nature of inverter-based RES can benefit the power system in terms of frequency stability support.

Renewable Energy: Completed Project

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Modelling and short-term forecasting of high wind speed events at operational wind farms

Project summary:

Loss of generation due to high wind speed shutdown represents an important challenge to power grid operations under high penetration of wind energy. This research presents novel approaches for the characterisation and forecasting of these events, using an ensemble-based weather research and forecasting model.

Project detail:

In the context of wind power ramping phenomena, High Wind Speed Shutdown (HWSS), potentially, represents the most severe risk to power system stability. It is clear from the available literature, that HWSS has not been extensively investigated to date. Although the need for forecasting and quantification of the impacts of HWSS feature strongly in the available literature, no models have thus far been formulated to describe this phenomenon, and no event-based forecasting models have been proposed in response to this research question.

This dissertation targets two major aspects of HWSS, namely the modelling, quantification, and comparison of the relative risk of HWSS events, and the short-term operational forecasting of HWSS events. It is evident from the literature that the development of a dedicated HWSS forecasting model will assist in the management and mitigation of the short-term risk associated with HWSS events. The development of site-specific models with which to quantify and compare temporal risk will, furthermore, aid in the siting of wind farms in regions with a low susceptibility for HWSS events.

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Modelling of an architecture for local energy generation and distribution with peer-to-peer electricity sharing in a South African context

Project summary:

The main aim of this project is to develop a Peer-to-Peer energy sharing model that considers the above mentioned gaps. The study uses the dissimilarity and complementarity of the load patterns in the South African residential and commercial energy sectors as an asset to implement the Peer-to-Peer energy sharing between the prosumers operating in these two sectors.

Project detail:

The main aim of this paper is to develop a Peer-to-Peer energy sharing model that considers the above mentioned gaps. The proposed system consists of two prosumers; a residential prosumer that employs a roof mounted photovoltaic system with energy storage capabilities, and commercial prosumer with a dual-tracking photovoltaic system. The prosumers are connected to each other by power lines for P2P operation. The developed model minimizes both prosumers' operation costs by maximizing the use of the power from the renewable energy sources; optimally managing the internal power sharing between the prosumers; and minimizing the use of the electrical utility operating with the Time-of-Use rate.

The study uses the dissimilarity and complementarity of the load patterns in the South African residential and commercial energy sectors as an asset to implement the Peer-to-Peer energy sharing between the prosumers operating in these two sectors.

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Matching renewable energy to the South African electricity system

Project summary:

The main motivation for this research was to determine how renewable energy can be incorporated reliably given the current South African electrical network infrastructure.

Project detail:

The main significance of this project was to provide South Africans with a framework in which reliable electrical power while reducing the reliance on fossil fuels. The main research question was: 'How does renewable energy affect the electricity system?'

By utilizing PowerFactory's highly flexible applications, different connection strategies under different penetration levels could be compared and the limitations of the electrical infrastructure illustrated. Matching renewable energy with Eskom's electricity transmission and distribution is necessary to ensure that the new power plants will be integrated to the electrical grid at the correct voltage and frequency and match the demand of electricity.

Based on the results, it was found that, renewable energy can be matched to the electricity system by correctly calculating the points of connection and the sizes of the system. However, although the socio-economic factors were beyond the scope of this research, the study showed that a decentralised system is more financially manageable for the utilities. Without too much modification to the current infrastructure or taking any customers off grid, decentralisation can help to better manage the grid stability and reliability. While the technical challenges associated with connecting renewables on to the grid are not unique to South Africa, South Africa unfortunately does not manufacture most of the associated technologies locally.

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Optimal energy management modelling of a grid-connected micro-hydrokinetic with pumped hydro storage

Project summary:

The results of the study revealed that the developed optimal energy management model for the proposed grid-connected micro-hydrokinetic river system consisting of a pumped-hydro storage system, proved to optimize the power flow, by minimizing grid consumption and maximizing the energy sales during peak periods. Additionally, the results of the study proved that the developed rule-based control algorithm was able to manage the load demand uncertainty problem since the open-loop optimization approach cannot cater for load forecasting error.

Project detail:

Hydrokinetic technology proved to be a promising renewable energy technology that can off-set the stochastic nature of solar and wind technologies. This study benefits ESKOM by creating an awareness on likelihood of electricity generation, using the flowing water resource found in lower reservoirs of the existing pumped-hydro storage plants. In this study, the developed optimal energy management model proved to successfully allow the proposed hydrokinetic system to power the pumping unit in order to store excess energy for later use, during high demand peak periods.

The developed model was tested while the proposed hydrokinetic system is used to supply the commercial, residential and industrial load, respectively. The model proved to benefits the three aforementioned load types by maximizing the energy sales and minimizing the grid consumption during peak periods.

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Dynamic modelling of traction loads and renewable energy systems on shared power lines for power quality assessment

Project summary:
The modelling of different renewable power plant inverters and traction rectifier technologies for accurate network planning and power quality assessment studies. An investigation into the impact of traction loads on the power quality assessment of renewable power plants through measurements and simulation.

Project detail:
The introduction of renewable power plants on traction networks presents new power quality concerns. Dynamic generic DIgSILENT PowerFactory models of various renewable system inverter technologies and traction rectifier technologies were designed for time domain simulation. Power quality measurements were taken at traction substations and at various wind farm inverters. To validate the accuracy of the models, the simulation results were compared to measured results. Due to good correlation, the models can be used for network planning and power quality assessment studies.

The power quality impact of traction on the power quality assessment of renewable power plants was further investigated. The assessment of voltage unbalance indicated that traction loads are generally the largest contributor to voltage unbalance on traction networks and can cause inverter trips at renewable power plants at certain conditions. An approach to assign harmonic current contributions of renewable power plants and traction loads interconnected on a distribution traction network is presented. The method allows for the exclusion of background harmonics generated by traction loads on the harmonic emissions assessment of renewable power plants. From a case study on the approach, results show that traction loads impact the harmonic assessment of renewable power plants and that present current assessment methods will not always provide accurate results.

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Assessment of geographical based load forecast approach in distribution planning

Project summary:

The 'legacy method' (LM) of electrical load forecasting, which entails historical load trending and collection of electricity customer applications is compared to the geographical load forecasting technique (GLF) which is based on spatial forecasting method. Both these methods are applied in power system distribution network.

Project detail:

The load forecasts from the real life case studies were evaluated on forecast accuracy, how they influenced the planning of adequate, reliable and economic (ARE) network infrastructure and their impact on the procurement and construction of the network infrastructure. The results revealed that the LM was more accurate than the GLF method in both the case studies that were evaluated. However, the GLF method showed to be supporting the planning of adequate, reliable and economic infrastructure better than the LM. It was found that the forecast error for the GLF and legacy method do not affect the utility infrastructure procurement and construction.

Renewable Energy: Completed Project

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Modelling the technical influence of randomly distributed solar PV uptake on electrical distribution networks

Project summary:
The overall purpose of this study is to propose a methodology with which to model the power supply from rooftop PV systems and with which to perform network studies on distribution networks, in order to identify the technical constraints that limit PV uptake, and to determine the PV penetration levels at which technical problems start occurring.

Project detail:
The stability and safe and successful operation of the local distribution grid is a direct concern for Eskom, since they are the network operator. The outcomes of this research will provide Eskom with essential information on the influence that solar PV systems will have on a distribution network. It will give insight into the capacity of solar PV systems that a distribution grid can handle, as well as provide information about possible network strengthening measures in order to accommodate a larger capacity of rooftop PV systems. The aim is to accumulate enough information that may be packaged together as a vital aid in the development of planning methodologies for future distributed generation and grid-connected solar PV systems. The overall purpose of this study is to model the power supply from rooftop PV systems and investigate how they may affect the local distribution grid.

10 Combustion Engineering Report

The Specialization Centre for Combustion Engineering has engaged in a brought spectrum of projects around the boiler and auxiliary plant. Each project was selected to address technical challenges for which a solution could provide potential benefits to Eskom.

Prediction of coal moisture in raw coal stockpiles: A model to predict the residual surface moisture content was developed based on experimental work, considering the size fractions of coal in a coal stockpile. It is now used in Eskom Primary Energy Division for coal moisture estimation. It will also be valuable for guiding coal contracts with suppliers in the future and ensuring that Eskom receives the quality of coal that it paid for. Development of a condition monitoring philosophy for a pulverised fuel vertical spindle mill: This project showed the possibility of implementing a mill condition monitoring philosophy which could have a significant financial impact on the milling plant of the fleet by shifting from outage based to condition based maintenance. The project demonstrated that condition-based monitoring could be achieved using existing measurement methods.

Measurement and prediction of coal flow rates in pulverised fuel pipes: The work led to an improvement in the PF flow measurement standard that was subsequently implemented and is currently used as an Eskom guideline. The work was based on extensive on-site testing and provided a critical review of the pulverised fuel flow testing methods used in Eskom.

Solid Particle Erosion of Ductile and Brittle Materials at Coal Fired Power Plants: The results of the study are being used to select erosion resistant material for PF boilers to reduce wear related maintenance costs. Development and design of mill de-sander for SA coal applications: The project led to design upgrade of desander technology that lead to an improvement in the PF classification process which will reduce boiler wear and reduce SO3 emissions by selectively extracting silica sand particles and pyrites.

Effect of biocides and bio dispersants on condenser tube fouling and thermal performance: The result of the project is currently implemented at Kriel Power Station and will improve the heat transfer characteristics of their condensers and subsequently improve the entire cycle efficiency. It also led to further work to improve the effectiveness of the use of a novel chemical treatment, to abate the formation of bio-fouling.

Dense phase pneumatic conveying of fly ash: The results of this project are being used to optimise the air consumption for the dense phase conveying system at Medupi by the researcher who is senior engineer at the auxiliary plant at Medupi. This will lead in substantial reduction in compressed air consumption.

Prevention of Dew Point Related Air Heater Fouling: This project resulted in the development of a modelling tool for Eskom that will be used to analyse air heater performance and the occurrence of dew point. The tool can be used for quad sector designs which are installed at Medupi and Kusile. Investigation work is already on the way to look at possible modifications that will lead to preventing air heater fouling caused by dew point occurrence. The tool has been validated using extensive measurements at Matimba Power Station.

Combustion Engineering Report *continued...*

Total air flow measurement using a multi whole Pitot tube: This current project will improve the total air flow measurement as required by the FFFR guidelines which is important for ensuring boiler safety and efficiency.

Evaluation of the quality of gypsum produced at coal fired power stations versus the market requirements in South Africa: The results of this project helps Eskom in the commercialization of Gypsum product from the Kusile plant.

The combustion engineering specialization center at Wits has contributed significantly to building a community of highly skilled industrial specialists within Eskom. Many of the MSc graduates have taken on key and positions in Eskom that have positively impacted Eskom's technology and engineering decisions. This has helped to fill the existing gap of SMEs within Eskom for which costly international and local engineering consultants were otherwise required.

11 High Voltage AC Report

The HVAC Specialisation Centre continues to provide a good Return on Investment (ROI) by training Eskom staff via conducting Eskom-focused research towards postgraduate degrees and by providing courses such as a course on high-voltage corona that was presented to Eskom staff in 2019. Other courses are being planned for 2020/21.

Power system projects have included tackling inter-area oscillations between the Koeberg power station generators and the generators at the Mpumalanga power stations and well as the effect of the recently installed wind farms in the Western Cape on the optimum settings for the Power System Stabilizers at Koeberg power station. Another project in this area involved an investigation into methods for increasing the amount of power that can be transferred along a transmission line corridor. Another project involved the real-time estimation of the amount of inertia on the Eskom network – this is becoming increasingly important with the integration of renewables that do not contribute inertia and thereby making the network more difficult to control.

An insulation coordination project involved investigating the possibility of increasing the nominal voltages of Eskom substations (e.g. from 88 kV to 132 kV) without the expense of replacing the busbar structures. The Eskom student who conducted this research presented his results at the prestigious Cigre General Meeting in Paris where he was awarded a Best Paper Prize.

In the asset management area, a project involved an investigation into methods for monitoring the condition of vacuum circuit breakers and an investigation into rotor thermal instability failures at Eskom power stations. Another project involved the detection of vibration sparking in stator bars at Eskom power stations which can lead to early insulation failure. Another project involved the optical monitoring of pollution on transformer bushings.

In the smart grids area, a project involved an investigation into improved monitoring of small distribution transformers. Another project involved designing suitable tariffs when both PV and EV are present at the distribution level. Another project involved automation of the response to faults specifically at the distribution level – a technique known as Fault Location, Isolation and Service Restoration (FLISR).

The HVAC SC also participates in Eskom SCOT committees in addressing Eskom electrical equipment issues. A PGDip degree that was initiated by the HVAC SC has been remarkably successful in attracting a large number of enthusiastic students (26 in 2020). The course content has benefitted greatly from feedback from Eskom SMEs and is providing training on the evolving power system (especially with the future integration of a large amount of renewable energy sources and smart grids).

12 Materials & Mechanics Report

The EPPEI Materials and Mechanics specialisation centre was established within the UCT Centre for Materials Engineering in 2012 to focus primarily on the high temperature behaviour of engineering materials, with emphasis on materials utilised in power generation.

The specialisation centre was founded on four main goals, namely (i) supervision of Eskom engineers registered for higher research degrees where projects are focused on solving Eskom challenges, (ii) development and presentation of short training courses in materials technology, (iii) establishment of partnership with developing university in order to grow materials and mechanics expertise, and (iv) enable technology transfer to industry where appropriate.

In particular, the research focus was directed at investigating and understanding the influence of service operating environments on the performance of materials with a view to being able to (a) better predict the life of engineering materials and components in power generating plant, (b) optimize the selection of materials for plant construction, (c) improve manufacturing technologies including welding and (d) improve the reliability in monitoring material and component integrity.

To achieve this, we recognised that training and research includes elements of physical metallurgy and metallography, structural integrity, high temperature behaviour (including creep), environmental degradation (including corrosion), welding metallurgy and processes, materials modelling, and non-destructive evaluation (NDE).

In order to address the goals outlined above, not only now and in the recent past but also in the future, we have fostered the growth of a very strong materials science and mechanics capability that extends across three universities, namely UCT, Nelson Mandela University and Stellenbosch University. The academic lead and primary materials testing capability is situated in the UCT Centre for Materials Engineering which is led by Professor Robert Knutsen. The main capability in materials characterisation has been established through the EPPEI-supported appointment of Dr Johan Westraadt in the Centre for High Resolution Transmission Electron Microscopy at the Nelson Mandela University. Partnership with Associate Professor Thorsten Becker at Stellenbosch University completes the picture by providing strong support in fracture mechanics and mechanical property assessment.

Together we have worked with Eskom, particularly the Research Technology and Development (RTD) division, to develop expertise in assessing, characterising and understanding materials damage. Through this collaboration we have successfully supervised Eskom engineers and non-Eskom students towards achieving masters and doctorate degrees, and in doing so, our knowledge and capability to provide ongoing support to Eskom has expanded. Additional collaboration with the University of the Witwatersrand and the University of Pretoria, particularly with respect to welding technology, has further strengthened our local capability to support Eskom.

Research highlights during EPPEI I and II include assessment of the weldability of service aged steam pipe, development of a complex model to simulate oxidation of nuclear grade stainless steel in a primary water reactor, optimisation of heat treatment to prevent stress corrosion cracking occurrence in turbine blades, method development for full field strain measurement during accelerated creep testing, and microstructural damage characterisation of service aged turbine rotor steels. The latter project has not only contributed to extensive savings by avoiding replacements incorrectly judged by the OEM, but it has also resulted in the ongoing development of rigorous protocols to assess material damage condition using advanced electron microscopy techniques. Our ability to link microstructure characterisation and mechanical property measurement in understanding material property and damage evolution during service contributes substantially to improving risk-based inspection practices and the ability to support Eskom in meeting challenges to ensure long term sustainable and affordable electricity supply in South Africa.

Ryan Matthews (PhD)

Oxidation kinetics of 316L stainless steel in the pressurised water reactor environment

Project summary:

This investigation measured the oxide growth kinetics of 316L stainless steel when exposed to a simulated primary water environment of a pressurised water reactor (PWR). It is generally accepted that intergranular oxidation at the surface of a metal forms a preferential site for SCC initiation; therefore the kinetics of both surface and intergranular oxidation was measured. The influence of temperature, within the range of PWR primary water (290°C, 320°C and 360°C), as well as the influence of starting condition (annealed, 20% elongated, 30% elongated and 20% cold rolled) was investigated.

Project detail:

Samples were prepared with the various starting conditions and exposed to simulated primary water, at the specified temperatures, for various durations from 1 hour through to several thousand hours to plot the oxide growth on a log scale time axis. Subsequent to the exposure tests, the Cr rich inner oxide depth was measured locally at selected locations. The surface and intergranular oxide depth was directly measured from cross-sections either with a transmission electron microscope for short duration exposures or, for longer exposures with deeper oxides, within a scanning electron microscope. No significant difference was noted on the oxide kinetics between the various starting conditions evaluated. Temperature, however, had a significant influence with oxide growth kinetics decreasing, rather counter-intuitively, as temperature increased through the measured range. In addition, a strong dependency on grain orientation was observed.

A modification to the Point Defect Model was proposed to arrive at a quantitative expression to describe surface and intergranular inner oxide growth as a function of temperature in 316L stainless steel, which accommodated the deviation from Arrhenius behaviour through the measured temperature range. Functions for both the rate constant, α_3, and the transfer coefficient, k_S^0, associated with the metal/oxide interface reactions were developed. The resultant model was able to predict, with reasonable accuracy, the growth of the Cr-rich inner oxide over time. The most consistent explanation for the deviation from Arrhenius behaviour was that the coherency across the metal/oxide interface degraded as the temperature increased through the tested temperature range. This would reduce the potential for ionic transfer across the interface necessary for the interface to migrate and increase the oxide depth.

Benefit to Eskom:

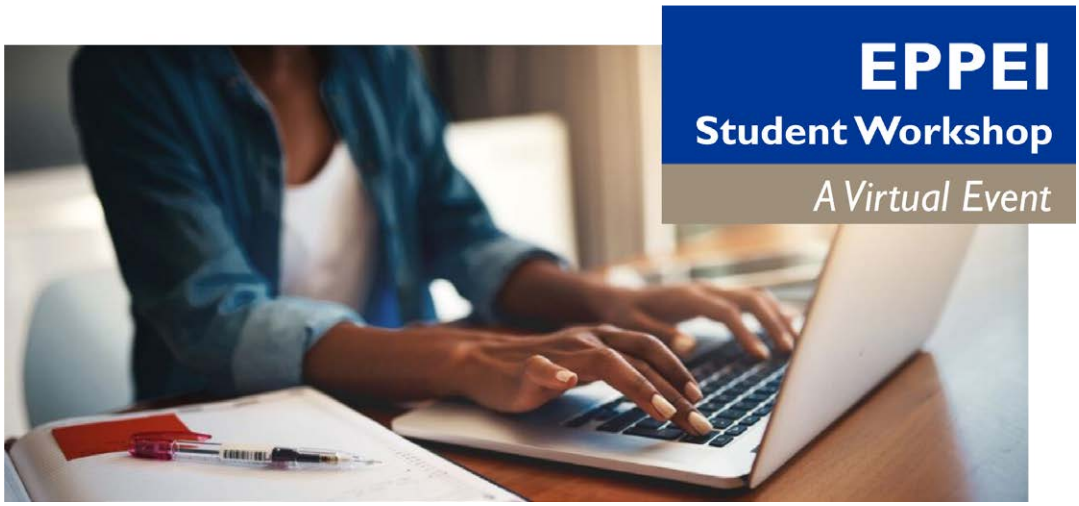
Since a similar temperature dependence on the growth of intergranular stress corrosion cracking (IGSCC) in the primary water environment has been observed within the same temperature range, it is proposed that the above explanation, observed in the absence of applied stress, extends to explain the behaviour of IGSCC kinetics in austenitic stainless steel and can be used by Eskom to predict possible onset of IGSCC.

13 EPPEI Student Workshop 2020

This year has brought about several changes and circumstances that have forced possibly every individual in the world to adapt to a new way of life and work. For EPPEI, it was no different. Our annual Student Workshop that brings together our EPPEI Community was held for the first time ever, as a virtual webinar event!

The workshop followed the same format as it did in previous years, and ran over two days, the 12th & 13th of November 2020. It was well attended and open to a bigger audience because there were no venue capacity limitations as it tends to be with physical events. There were several guest speakers in our panel discussion sessions, which were incredibly informative. The students showcased their work via presentations which were beautifully presented during the webinar – they all did an amazing job.

A massive thank you and well done must be extended to the entire High Voltage AC Specialisation Centre team at UKZN, who were responsible for the planning and organising of the event. Our hope is that South Africa will soon overcome the pandemic and that we can look to a physical Student Workshop come 2021.



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