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THE OFFICIAL PUBLICATION OF THE SOUTH AFRICAN INSTITUTE OF ELECTRICAL ENGINEERS | FEBRUARY 2018

# INFRASTRUCTURE Indaba

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## Register Now For The Cesa 2018 Annual Infrastructure Indaba!

The CESA Infrastructure Indaba is a two-day conference that brings together leading experts including government officials, consulting engineers and built environment professionals for the purpose of improved delivery and management of public infrastructure. The event aims to foster partnerships between government and the private sector, particularly the engineering sector, and capacitate the channels of service delivery through cooperation and the development of common goals.

With the theme: 'Engineering the future now', the Indaba provides a platform to engage, network and share best practice required for improved service delivery within the built environment with the following topics being deliberated:

- Infrastructure Development
- Engineering the Future
- Public & Private Investments - Capital Intensive Infrastructure Projects
- Water Security – 'Water is Life for Communities': Role of Clients and Consulting Engineers
- The Transformation Journey
- Leadership: Delivering Value for Money in Infrastructure Procurement
- Leadership: Industry Integration and Engineering Collaboration
- The Politics of Infrastructure

Enquiries can be directed to Bonolo Nkgodi at
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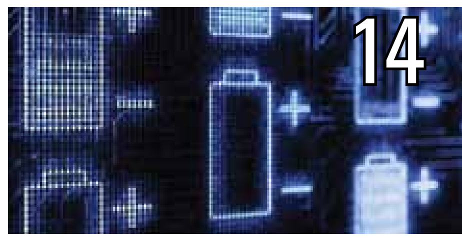





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Dear Valued Reader

This issue of **watt**now features Energy - solar, efficiency, green renewables, etc.

This issue is jam-packed with plenty of feature articles. Our first feature (pg 14) discuss the Key Learning of a Battery Energy Storing Testing Facility, presented by Peter Lanley and Ronel Clarke from Eskom, at the 2017 SAIEE SmartGrid Conference.

The Bakhe Nleya and Philani Khumalo, from the Faculty of Engineering at the Durban University of Technology, presented "Energy Efficiency Consideration with Cloud Support" at the 2017 SmartGrid Conference and makes for a very interesting read, on page 22.

Edwin Cartlidge wrote an article on how the Chinese laser sets power records, where physicists are planning to build lasers so powerful they could rip apart empty space! Read more on page 28.

Page 34 features and article on an all-sector energy roadmap for 139 countries on how 100% clean and renewable wind, water and sunlight can reverse global warming.

The next issue of **watt**now, is in the works, featuring Digital - Cyber Security, Digital Economies, Identity technology and Productivity - deadline 2 March. If you would like to contribute, send an email to me - minx@saiee.org.za. You earn CPD credits if your article is published in the magazine.

Herewith your February issue - enjoy the read!

Minx

Earn CPD Credits *Visit www.saiee.org.za to answer the questions related to these articles to earn your CPD points.*

## JACOB MACHINJIKE
## 2017 SAIEE PRESIDENT

This month, the wattnow theme is energy.

February is the shortest month of the year and brings with it heightened strength and vitality required for sustained physical and mental activities related to our goals - this is energy.

Some refer to February as the month of love, and many of us recall this month, 27-years ago, when Nelson Mandela was released from prison and he marched the streets of Cape Town as a free man.

One of the quotes attributed to Nelson Mandela sums up this month for me, "There can be no greater gift than that of giving one's time and energy to help others without expecting anything in return."

Einstein developed a law that states that energy can be neither created nor destroyed; rather it can only be transformed from one form to another.

Generally, energy is power derived from the utilisation of physical or chemical resources. The landscape across the world is changing. Climate change is part of this change but the increase in availability of shale gas as well as that of cheaper and more efficient renewable plants, are also driving changes. These changes have socio-economic impacts.

Communities, traditionally reliant on the opportunities and jobs available from the coal and oil industries together with the production facilities associated with these, are impacted. Utilities and consumers are also affected. Electrical utilities across the world are under pressure as a result of the large-scale introduction of renewable generation competing with utility generators and a dwindling customer base. This is caused by technologies such as solar photovoltaic placed on rooftops or on customer premises to consume less energy from the utility. This results in the so-called "utility death spiral". Utility death spiral refers to the feedback loop where grid-wide fixed costs divided by a shrinking pool of customers drives up rates, causing more customers to go off-grid. As customers reduce their use of grid electricity using solar, wind or other off-grid technologies, the customer base needed to cover the utilities' fixed costs reduces, putting upward pressure on rates and presenting negative impact on the finances of the utilities.

Renewable generators are often treated as "must run" plant, due to low short run marginal costs, and are dispatched first to supply demand. Dispatchable generators and traditional utility units, then focus on the residual demand.

Apart from not being dispatched, renewable plant such as wind and solar PV are also intermittent.

Increases in non-dispatchable equipment and intermittency will require more and more flexibility from the dispatchable plant on the system and in time this will require the addition of different types of plant, such as gas fired stations to ensure system reliability.

The changing production system requires planners and designers to pay more attention to aspects such as inertia, frequency control and the provision of ancillary services from where it will be provided. Considerations in the design of networks should incorporate technologies such as batteries for energy storage. Renewable plants will have to evolve to be able to provide the same services as traditional plant.

Some customers can use the opportunities provided by the technologies now available to separate from the grid, or reduce the dependencies from the utilities that have historically provided them with electricity, or become "prosumers" (both consumers and producers). Other customers that cannot separate from the grid may be adversely impacted as they will face ever increasing tariffs, due to the need of the utility to recover fixed costs from a reducing customer base. In South Africa the block incline tariff will present real challenges to Regulators, Municipalities and Eskom.

When the people currently in the top end of the block incline tariff get out of or reduce their consumption to the bottom of the block incline tariff, or leave it completely, the subsidies designed into this tariff will no longer be possible. Large Industrial customers could adopt technologies to reduce dependencies on the grid and thus avoid the ever-increasing costs.

A death spiral, indeed!

Substantial changes are required in how the electricity system is managed.

South Africa will have to adapt and make choices that will ensure the reliability as well as the sustainability of the system.

*J Machinjike | SAIEE President 2017*
*Pr. Eng | FSAIEE*

# SAIEE Celebration

*From left: Stan Bridgens (CEO), Minx Avrabos (Managing Editor), Max Clarke (Birthday Boy), Gerda Geyer (Events Secretary) and John Gosling (Mentorship).*

*Max still goes down on his knees without difficulty! He says: "The secret to longevity is happiness!"*

It was on a rainy 15th February when the SAIEE Staff and members of the Historical Section celebrated Council Member, Fewllow and Past Honorary President Max Clarke's 92nd birthday. Max has been an SAIEE Member for 72 of those years!

We were entertained to a brief history of when he were a young engineer, starting his career in 1947 and how he met the "Australian" (his wife) which had us all in stitches.

Stan Bridgens, SAIEE CEO presented Max with a gift from us all and added: *"Max, thank you for all your hard work and keeping us awake every Thursday".*

Max is the Chairman of the Historical Section and attends most the Thursday 'work-parties' at SAIEE House when aertefacts are identified, restored and the SAIEE Museum maintained. We wish Max all the best for 2018.

*From left: Stan Bridgens, Max Clarke and John Gosling.*

*Max receiving his gift.*

*From left: Lerato Mulovhedzi (IT) and Connie Makhalemele (Membership).*

*Joanne Griffin (Membership)*

# DEHN Africa to bring lightning protection and education to schools in SA

South Africa is a country whose residents are highly susceptible to lightning strikes for a number of reasons. These include the country's overall high lightning flash density per square kilometre, its relatively large rural population, whose members arguably do not have access to safe shelter in work, home and school environments, and a lack of education around the dangers of lightning.

*"The average number of annual lightning deaths in South Africa is not always easy to estimate,"* says Hannes Ackermann, Managing Director of surge protection, lightning protection and safety equipment company, DEHN Africa. *"It could easily be as high as 500 deaths per year or more. The South African Weather Service has estimated a figure of over 300 recorded deaths, while simultaneously noting that this number could easily be skewed higher, as it is based on verified cases of people taken into health institutions, and then mortuaries, after being struck."*

Ackermann notes that there is a well-established body of facts on both lightning and the promotion of lightning safety, but that the greater challenge in South Africa is how to promote and share this information. *"There is a real need for people to become more knowledgeable about the risks of this extraordinarily powerful natural phenomenon. DEHN Africa has decided to try to change attitudes and promote education on lighting by introducing a programme in schools that explains and advises pupils on some of these topics. Not only do these institutions lie at the very centre of our communities but in addition children, as the most vulnerable members of our society, are also victims of lightning strikes from time to time. At DEHN Africa, we feel that lightning deaths are always unfortunate, but that when we see media reports on the deaths of children then the story truly becomes tragic."*

Ackermann notes just a few fairly recent examples of media reports on the deaths and injuries of children from lightning strikes:

- In May 2017, three girls were struck by lightning in the Kroonstad area in the Free State on the way to school, of whom one girl was critically injured before being stabilised by medical personnel, while the other two were fortunate to receive more minor injuries.
- In October 2017, two children were struck by lightning – fatally - in rural Kwa-Zulu Natal while walking to school.

These few examples are just some of the headlines showcasing the passing of schoolchildren in South Africa due to lightning strikes. Ackermann says there is an urgent need in South Africa for education around lightning safety, and that beginning with our children is a noble and yet also practical start to further community empowerment.

He says, *"DEHN Africa has previously carried out lighting protection installations in Uganda, to excellent effect, and we propose carrying out two projects at two schools in South Africa. DEHN is looking at ways to fund and expand on this type of project and we have already engaged with stakeholders to identify the way forward, plan and undertake projects of this type. Part of the project objective will be to offer training and education to both children and teachers, even extending it to parents where necessary.*

*"We thus anticipate, hopefully, that in this way the learners and educators will thereafter spread the word about some of the practical dos and don'ts of lightning protection and safety within their wider communities, in this way helping others who are not directly attached to the schools,"* Ackermann concludes.

# PowerGen Africa pre-event Cocktail Party - who's who?

POWER-GEN & DistribuTECH Africa conference and business expo recently hosted an exclusive pre-event cocktail reception in Sandton. The opportunity to engage with leading stakeholders in the sector, coincided with the POWER-GEN & DistribuTECH Africa advisory board meetings.

*Chris and Mark Yelland of EE Publishers with Minx Avrabos, Managing Editor of* ***watt****now.*

*Sindy Mzamo, COO, Edison Power Group and Nigel Blackaby, Director of Conferences, PennWell.*

*Feraye Gurel, Event Director of PowerGEN & DistribuTECH Africa, Sindy Mzamo, COO, Edison Power and Renita Moonsamy, MD of Lontocoal Asia.*

## CESA Focuses On Effective Ethical Leadership – 'Our Future Is Now!'

*From left: Chris Campbell (CESA CEO) and Neresh Pather (CESA President).*

Consulting Engineers South Africa's (CESA) newly appointed President, Neresh Pather, presented his presidential message and theme for the year at a function held in Johannesburg recently.

Pather's focus for the year will be on Effective Ethical Leadership with the theme of 'Our Future is Now!' He stated that change can be effected if we believe in it and work hard enough to achieve it and that with great leadership we can succeed!

Pather began his presentation by stating, *"The world of the future can only be changed and facilitated through the leadership of today embracing the true purpose of service to humanity"*.

He said that having had a smooth ANC Leadership Race that concluded during December 2017 he believes that we are on a journey to restoring confidence in our country and its leaders and this includes the recent successful trip by our leaders to the World Economic Forum in Davos. Pather believes that leadership starts with Values and Purpose that underpin Governance and Process.

During the year Pather will be focusing on the following key objectives: Effective Ethical Leadership most importantly creating role models that inspire our future generations; Transformation efforts in changing people's hearts and minds; Embracing the 4th industrial revolution, the new world of digitization and new ways of doing things through innovation and data informed techniques; Industry integration and working collaboratively on common issues that benefit industry and society; and Working with industry clients in addressing Corruption, Governance, and Client leadership.

Planned programmes for employment creation, skills development and encouraging trade relations with our neighbours, developed and emerging countries should be accelerated.

## The Explosion-Proof Absolute Encoder That Will Fit Where Others Won't

Many applications that require the use of absolute encoders are demanding, not just from a performance perspective but also because of the operating environment.

An example of this is applications where the encoder has to be explosion-proof due to the dangerous atmosphere in which it operates. Another would be applications that involve harsh environmental influences such as offshore platforms or those that experience huge shock loads of over 100 Gs or even shaft loads of hundreds of Newtons.

The Hengstler AX65 absolute encoder has been engineered to handle all these requirements, and is believed to be one of very few devices that can do this.

The Hengstler AX65 is available from Countapulse Controls. The company has a strong customer service ethic and offers strong engineering and technical support.

## Latest Two-Year Frame Contract Awarded To Actom Power Transformers By Eskom Incorporates Extended Power Range

A multimillion rand two-year frame contract awarded by Eskom to ACTOM Power Transformers in early-2017 represents an extension of the range of power transformers covered compared with the previous frame contract.

The current contract, effective from April 2017 through to March 2019, covers the production and supply of power transformers of 1,25MVA up to 160MVA at 132kV, encompassing both standard double-wound units and autotransformers.

The previous equivalent two-year frame contract, which ended in 2014, covered standard transformers from 1,25MVA to 80MVA at 132kV.

*"The latest contract not only covers the production and supply of units up to 160MVA, as against up to 80MVA in the previous contract, but it also caters for the provision of autotransformers in addition to standard units,"* commented Wilma Muller, ACTOM Power Transformers' Project Manager.

In the period between the expiry of the former contract in early-2014 and prior to the award of the latest contract, ACTOM Power Transformers commenced production of autotransformers as part of a series of expansions and upgrades undertaken at its Wadeville, Germiston, plant, which resulted in substantial extension of its production capacity as well as its design, manufacturing and test capabilities. The latest expansion and upgrade of ACTOM Power Transformers' plant and test facility, completed in 2013, raised the top level transformer it is capable of producing to 315MVA at 275kV.

During the interim period between the two sets of frame contracts the government introduced new regulations aimed at encouraging the further development of local manufacturing capabilities and capacities by affording local manufacturers some measure of protection against foreign imports through the introduction of more stringent local content requirements for products and equipment purchased by state-owned enterprises. At the same time it designated locally-produced items to be purchased and used by parastatals for all infrastructural development, refurbishment and maintenance under their control.

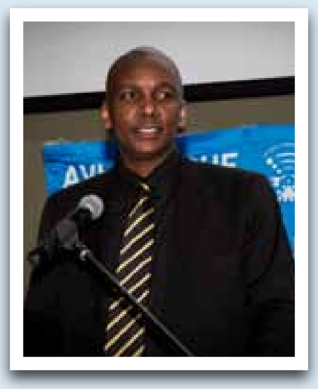
Locally-manufactured power transformers, among many other items of electrical and infrastructural equipment, have been so designated.

Consequently more stringent local content requirements apply in Eskom's current frame contracts for power transformers than previously. "Any transformers we produce and supply between April and December 2017 are required to have a local content of not less than 70%," said Muller.

*"Orders we've received under the frame contract to date include one for a 160MVA autotransformer, which is to be delivered in August 2018,"* she added.

Prior to the award of the present frame contract ACTOM Power Transformers underwent a factory accreditation audit conducted by Eskom to confirm that it qualified to meet the contract conditions. *"It resulted in us being named an approved producer of power transformers for Eskom up to 250MVA at 275kV,"* Muller stated.

## Chartering New Territories Through Aviation



*Thabani Mthiyane*
*ATNS CEO*

According to the International Air Transport Association (IATA), Africa will be one of the fastest-growing aviation regions over the next 20 years, with annual expansion averaging nearly 5%.

This ultimately means that, if nurtured, incredible economic opportunities await the continent's 54 nations.

Statistics show that currently the aviation industry supports 6.9 million jobs. R1.2 trillion of the economic activity on the African continent comes from transporting approximately 70 million passengers annually.

As an organization heavily embedded in innovation, engineering and information technology, ATNS is focused on development and creating a local independent economy for the aviation industry.

The South African Council for Scientific and Industrial Research (CSIR) and the Air Traffic and Navigation Services (ATNS) SOC Ltd recently signed a Memorandum of Understanding (MoU) to collaborate on a national multi-static passive radar facility. The CSIR and ATNS will join forces to establish a technology base that will be utilised to establish solutions in partnership with local industry.

# Schletter mounting systems for large-scale solar farm in China

The Schletter Group has completed another ambitious major project in China: The Anhui Jin solar farm in Anhui Province, China, generates 35 MW and produces electricity for nearly 20,000 households. With this, the Schletter Group continues its growth strategy in China.

*"We are already in an excellent position in the fast-growing Chinese market,"* Florian Roos, said. He is Managing Director of the Schletter facility in Shanghai, where the mounting systems for the project were manufactured. *"This project, which is particularly demanding due to its topography, contributes to further strengthening our reputation as a leader in terms of quality."* The Schletter Group employs over 450 people in Shanghai and, with a total of around 2.5 GW of installed PV capacity, is one of the largest foreign suppliers of PV mounting systems in Asia.

The solar farm is situated in hilly terrain with slopes of up to 30 degrees. In order to guarantee the stability of the facility in the sometimes steep and changing terrain, Schletter engineers first carried out a geological survey. On this basis, the installation was then individually designed. The PV mounting system used for the solar panels was Schletter's FS AS UNO. This single-support system has a solid ramming foundation made of hot-dip galvanized steel and is therefore particularly stable and durable. In addition, a high degree of prefabrication enables fast and easy assembly and thus high economic efficiency. Despite the sometimes steep terrain, the plant could be completed within as little as three months.

The system was installed by the contractor Shan YD EPC. Schletter had previously trained their technicians on site. The Schletter Group has already collaborated with Shan YD on several occasions, including a 5 MWp greenfield installation using the FS Duo system in the northern Chinese province of Heilongjiang.

The Anhui Jin solar farm is to be expanded by a further 15 megawatts in the coming months.

# Partnerships Key As SA Tackles World-Class Gamsberg Zinc Project

At Vedanta Resources' Gamsberg mine in the Northern Cape, Zest WEG Group is working closely with lead contractor ELB Engineering Services as a preferred supplier to standardise on its range of transformers and motors across a number of on-site applications.

The Gamsberg project is South Africa's largest current greenfields mining project, and will exploit one of the world's largest zinc deposits. It is being developed at a capital cost of US$400 million and is expected to produce 250,000 tonnes a year of zinc metal in concentrate.

*"This is a very exciting project for South Africa, especially as we haven't seen a new mine being developed in the country for many years,"* says Dr Stephen Meijers, chief executive at ELB Engineering Services. *"Vedanta Resources has shown real intent in terms of investment in South Africa; not only in this project but in others, and we are proud to be building Gamsberg."*

ELB Engineering Services' first package of work was the provision of water from the Orange River to the process plant, through an upgraded pump station and a pipeline of about 40 kilometres. The second package is the supply of power from the existing Eskom switching yard via overhead lines to the mine, and the third is the process plant itself covering all aspects from run-of-mine tip through to final product, including process dams and balance of plant.

*"First product is expected through the plant by the middle of 2018, with the civil works being largely completed by the end of the second quarter of 2017,"* says Dr Meijers. *"Structural and mechanical construction on the plant is now starting to become the focus of work, and the pace will continue to be intense until middle of 2018."*

Extreme temperatures on site – down to minus 10 degrees Celsius at night in winter and up to between 45 and 50 degrees in summer during the day – have affected the design and the construction methodology, he says. This has meant making optimal use of the cooler hours in summer, even pre-manufacturing as much as possible at night before placing during daylight hours.

Dr Meijers is a strong believer in partnerships, with much of the project technology being applied through exclusive partnerships with preferred suppliers.

*"We've worked with Zest WEG Group for many years, and appreciate their professionalism, quality of service and reliable scheduling,"* he says. *"We have therefore placed a number of the contracts for this important and fast track venture through Zest WEG Group companies."*

# Best of the energy sector brains trust submits papers for POWER-GEN & DistribuTECH Africa

Changing priorities and new imperatives emerged this month, as the POWER-GEN & DistribuTECH Africa Advisory Board met to review papers submitted for the POWER-GEN & DistribuTECH Africa 2018 conference.

After two days of review and discussion in Johannesburg, the expert international advisory board members reported that this year's paper submissions shed light on a range of new trends in the power sector across Africa.

Dr. Willie de Beer, chairperson of the POWER-GEN & DistribuTECH Africa advisory board, said: *"There is a significant acknowledgement of the disruptive landscape that we are operating in."*

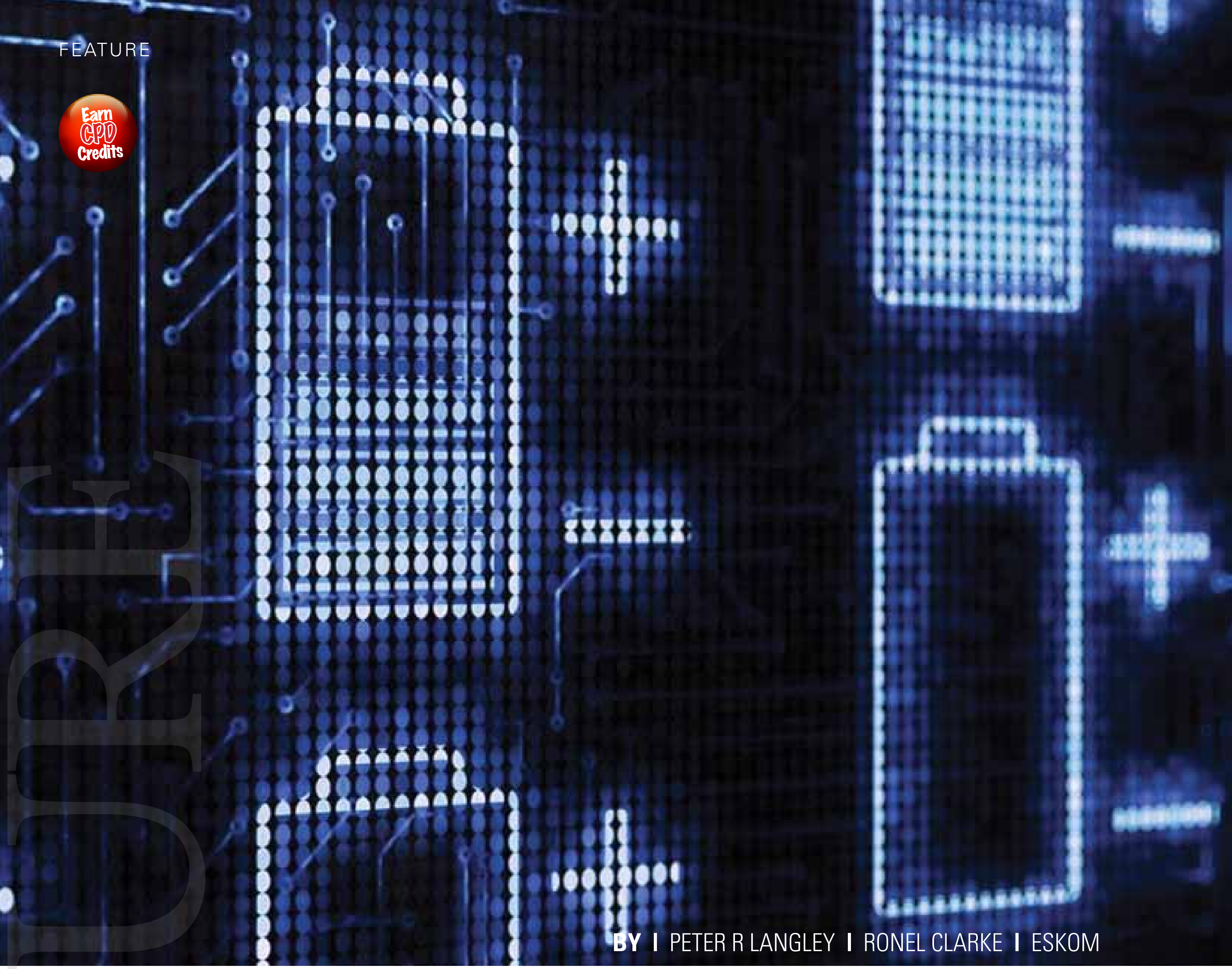
There is growing urgency among players to address issues such as developing continent-wide, integrated strategies to deliver power to the estimated 650 million who still have no access to power. Utilities' balance sheets and business models are also in the spotlight; as is the impact of digital technologies on the sector as a whole.

These new themes will be key focus areas at the POWER-GEN & DistribuTECH Africa conference, in line with the event's ongoing mission to deliver high-level, superior content to its 3,000 delegates.



Book your place at the POWER-GEN & DistribuTECH Africa conference before 15 June to benefit from the Early Bird rate. South African delegates are eligible for a 30% discount on conference fees if they book before 15 June. Choose from the full 3-day package including access to all conference sessions, the exhibition area, B2B meetings, lunches and networking events, or select the discounted one-day package. Read more about the advisory board's deliberations, and review package information at www.powergenafrica.com. Entrance to the exhibition area is free.

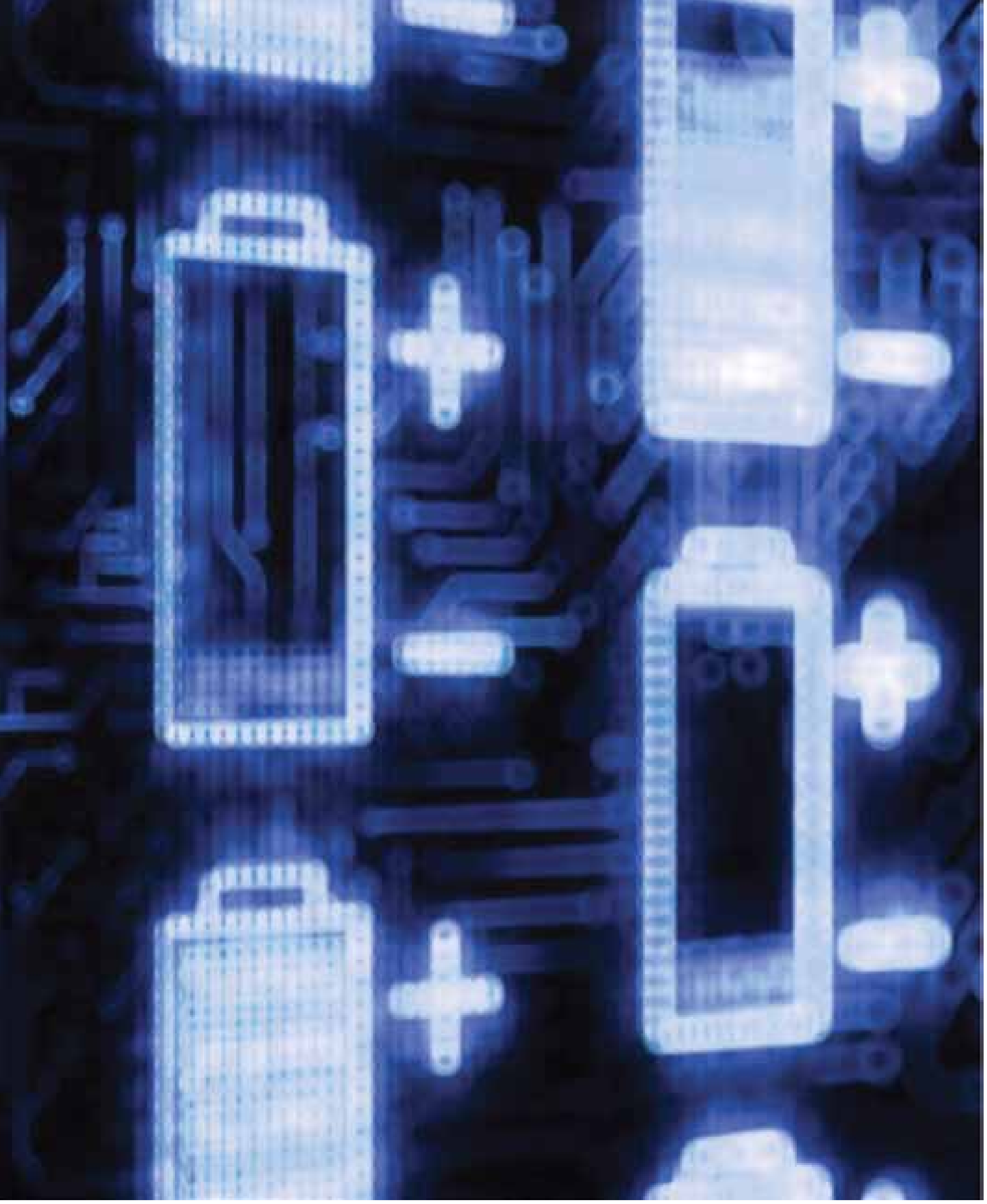
Earn CPD Credits



BY | PETER R LANGLEY | RONEL CLARKE | ESKOM

# Key Learnings of a Battery Energy Storage Testing Facility

The importance of energy storage within Eskom has been identified and necessitated research to be conducted in this field. Based on the research conducted, the need for a Test and Demonstration Facility was acknowledged.



A number of value streams can be derived, from the installation of energy storage, 27 value streams have been identified, and the stacking of these value streams aids in the feasibility of a technology for a specific installation. In order to achieve the maximum value from a battery storage system it must be able to perform all, or as many as possible, of the activities needed by the grid. This raises questions such as: Does the high power battery have sufficient energy capacity to allow load shifting? Does the high energy capacity battery react quickly enough to perform frequency regulation? Is the battery designed to provide multitasking, or is it suitable to a single value stream only? What will be the real value to Eskom of installing a specified battery technology into the grid?

Eskom Research has been investigating battery energy storage for more than 10 years, during which time it has identified nascent technologies for Large Scale Energy Storage for Utilities (larger than 1MW, 6MWh). Many of the early technologies were developed for other purposes, such as electric vehicles (EV's) and therefore exhibit features that are not a requirement for Utility applications. For example, EV batteries require being lightweight and having a small footprint, whereas a Utility battery does not have size nor weight limitations. These unnecessary additional features add to the cost of these batteries. The South African grid has an increasing quantity of variable renewable energy sources and the number of these IPP sources will further increase over the next 10 years. The Irish grid became unstable when 7% of renewable energy was introduced to it and as a consequence they have been rapidly adding energy storage and open cycle gas turbine (OCGT) capacity to allow increased renewable penetration. In 2012 less than 10MW of battery storage was installed worldwide, but in the year 2015 alone, a further 216MW of battery energy storage was installed globally.

The "Comparative Table of Energy Storage", produced annually by Eskom Research, has identified at least 50 different types of storage devices that could be used within the Eskom grid. Some devices are better suited to certain applications, whilst others may only be suited for limited support. The parallel operation of these devices under

# Energy Storage Learnings

*continues from page 15*

pre-determined test conditions will allow Eskom to evaluate the performance of the devices that are likely to be used in the grid and to determine their suitability and real lifetime operatingcosts.

## OBJECTIVES

Eskom Research has recognized that the future grid will need to incorporate energy storage in significant quantities and hence requested funding for the construction of a Test and Demonstration Facility at Rosherville in 2012. Whilst most large scale battery systems are at pre-commercial status, some are being offered on a commercial basis. These units remain expensive and are generally bespoke systems designed for the client's specific needs. Early testing of such units would allow Eskom to have a practical insight into the implementation and integration of such units into the grid and would empower to make purchase decisions based on the real operating data obtained from the Facility, under South African and Eskom conditions.

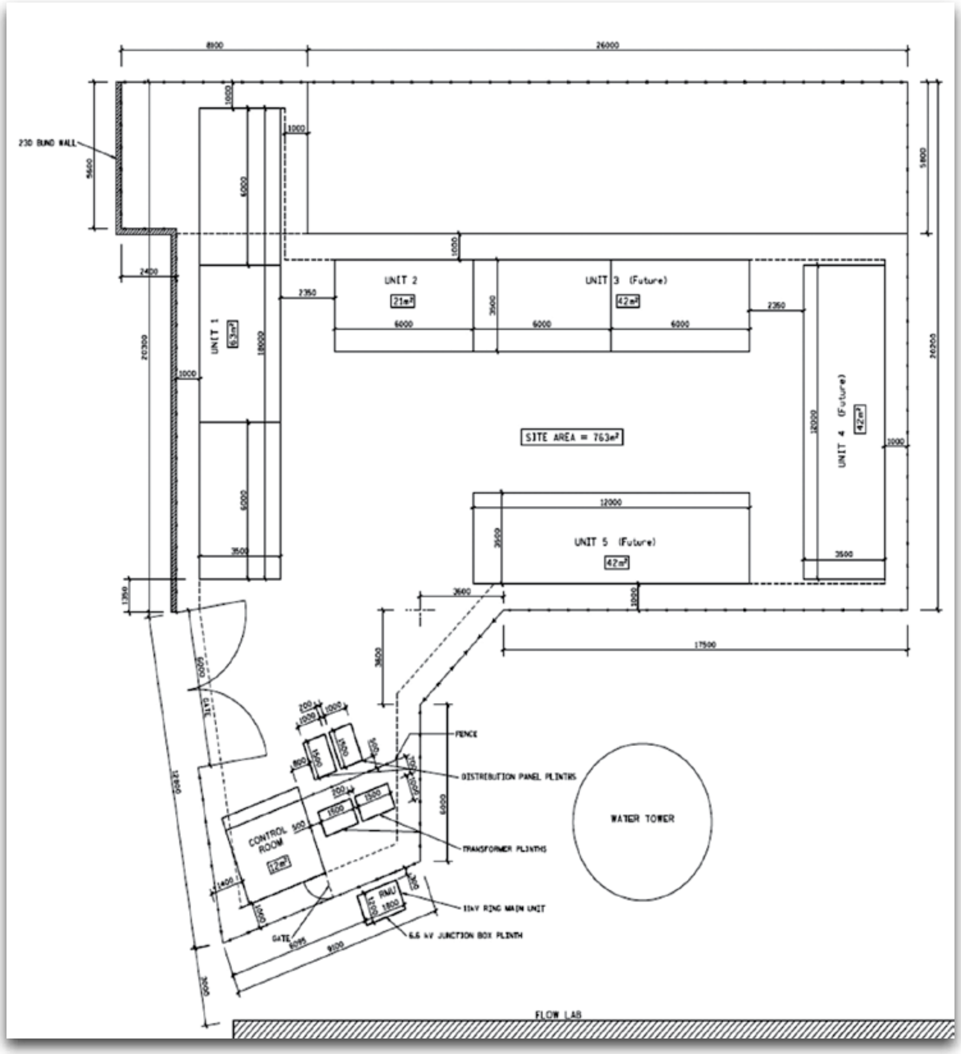



*Figure 1. Site Layout*

With the development of Advanced Batteries come many technological risks and exorbitant claims by the manufacturers. Whilst these claims may be valid under specific laboratory conditions, they often prove less valid under practical operating conditions.

The use of the wrong type of device in the wrong application can increase costs considerably and also lead to early failure of the device. Comparative testing of the various types of battery will establish which technology is most suited to which application.

In order to achieve the maximum value from a battery storage system, it must be able to perform all or as many as possible, of the activities needed by the grid. This raises questions such as: Does the high power battery have sufficient energy capacity to allow load shifting? Does the high energy capacity battery react quickly enough to perform frequency regulation? Is the battery designed to provide multitasking, or is it suitable to a single value stream only? What will be the real value to Eskom of installing a specified battery technology into the grid?

## DESIGN OF TESTING FACILITY

### A. SITE LAYOUT AND CONSTRUCTION

The site layout was designed to suit the allocated area adjacent to two existing test facilities on site (i.e. both the Flow Lab and the Drop-tube Furnace areas). The original design, accommodated five storage units, with one of the slab areas intended to house two separate units. However, once the tenders were received, the design of the systems, and in particular the non-modular design of the General Electric system, meant that the developed area could only

accommodate four units, with space for a future fifth unit being made available at the top of the Site Layout, as shown in figure 1.

The original design of the civil works included a slab of a minimum size of 12m by 3.5m that was installed on the same level as the existing ground, which provided a slight fall (approximately 50mm in each direction) for rainwater run-off. It was anticipated that this slight out of level would not affect the Energy Storage units and the difference would, in fact, be beneficial to avoid water build up.

In the event, both manufacturers insisted on their units being exactly level (within a tolerance of less than 1mm) and the units sit on packers under the mounting points.

The unit produced by BYD in China (Build Your Dreams) was even installed on large concrete legs, supplied by BYD, some 900mm high, so that the unit itself would be well above any potential flood levels.

It should be noted that a considerable saving can be achieved on future units by the use of foot pads, for example using large paving stones, which can be approximately levelled when installed at the predetermined location of the mounting points, rather than a full slab. The BYD small container has been installed partially in this fashion, as BYD wished to have a space between the two containers.

**B. BATTERY SYSTEMS**

An open tender was issued for the supply, delivery, installation and maintenance of battery energy storage systems with a capacity of 200kW 1.0MWh. It was a requirement that the systems must include all equipment to operate as standalone units in totality; therefore it needed to include a power conversion system, a battery management system (BMS), air conditioning units or heating systems and internal fire protection equipment required to protect the battery.

An additional requirement was for inclusion of current transformers and connection to the respective BMS to collect and record data from the system, as the AC charge and discharge as well as the DC charge and discharge will be monitored during the testing period in order to evaluate the individual performance of the battery and the power conversion equipment, to determine the availability and round trip efficiencies of the battery energy storage systems.

Two units were selected for the test facility, which included a BYD lithium-ion phosphate battery and a General Electric sodium nickel chloride battery.

**C. DATA RECORDING AND CONTROL EQUIPMENT**

The system consists of an outside 400V control cabinet, which contains the main incoming (1MW) breaker and five separate battery unit breakers of 200kW each. Each breaker is monitored individually via Current Transformers and Voltage Transformers contained in this cabinet.

The results are displayed on the metering cabinet inside the Control Room, as per figure 2, and are also displayed on the graphical computer representation (figure 5).

*Figure 2. Control Room Metering and Protection Cabinet*

*Figure 3. Control Room Grid Protection Panel*

# Energy Storage Learnings

*continues from page 17*

The information from these two cabinets is collected by the D400 interface, which in turn provides both the Citect Server and the data collection computer with this information. The Citect Server also has an internet interface, which allows for remote interfaces, via the Team Viewer software programme. The D400 interface is the standard interface used by Eskom at all its power stations and sub stations, and could be connected to Eskom's National Control at Simmerpan, if required at some point in the future.

In addition a grid control panel (figure 3) is also inside the Control Room, which incorporates all the grid protection equipment. This includes a "Loss of Grid" protection relay, an F60 Grid Protection relay, which monitors frequency, voltage, and droop or sag events, and prevents "dirty" power from being sent into the grid.

*Figure 4. Battery Back Up and Communications Panel*

An ION 7650 meter is also included, which monitors the Quality of Supply, including the various harmonic components which could result from the battery inverters. This information is also trended within the Citec system.

The information is displayed on the desktop computer screens in the control cabinet and all operator interfaces are controlled through this interface. The system is controlled via individual schedulers for each battery within the system, which can be accessed via these screens. The scheduler can be set to provide different output modes for specified periods of each day, so that the units can be charged during the off-peak night time period and discharged at pre-determined times each day.

Alternatively, the systems can be manually operated (typically by Central Control) when grid demand reaches a set level, or they can be programmed to maintain a variable output from a renewable resource.

The system is designed such that we can simulate variable outputs from a theoretical renewable source, or that we can connect to a real source remotely, via the internet. In this way, the ability of the Energy Storage systems can be demonstrated to provide a totally firm, despatchable output from a fluctuating source of supply.

The design of large energy storage systems includes an isolation transformer between the system inverter and the grid. This isolation transformer ensures that the storage system output is matched to the grid and also prevents any stray currents or electrical problems within the storage system from impacting on the grid.

The simplicity of the system allows centralised control, for example from Eskom Central Control Centre, to occur, as well as duty cycle development and simulation to be done by the qualified research staff.

**D. TESTING PROFILES**

Testing is conducted over a 90 day test basis, with various modes of output being tested for the full duration of the testing period. These include, but will not be limited to:

- Load shifting - 6 hours continuous output at 200kW per battery, off-peak charging available for 8 hours per day, each day for the 90 period.
- Wind smoothing - A typical wind farm daily profile established from a South African wind facility, (under afternoon storm conditions) which is used to supply the battery and/or grid, on a daily basis for 90 continuous days, with the battery expected to absorb and discharge to smooth the output.
- Solar smoothing - A typical solar output established from a South African photovoltaic facility (under cloudy conditions) is used to supply the battery and/or grid, on a daily basis for 90 continuous days, with the battery expected to absorb and discharge to smooth the output.
- Power Quality - The battery will operate at the top end of its charge and smooth out frequency and voltage changes resulting from demand changes.
- Other – The facility is a tool for Eskom to simulate actual conditions and to complete predictive testing prior to selection, design and installation of battery energy storage systems on the network.

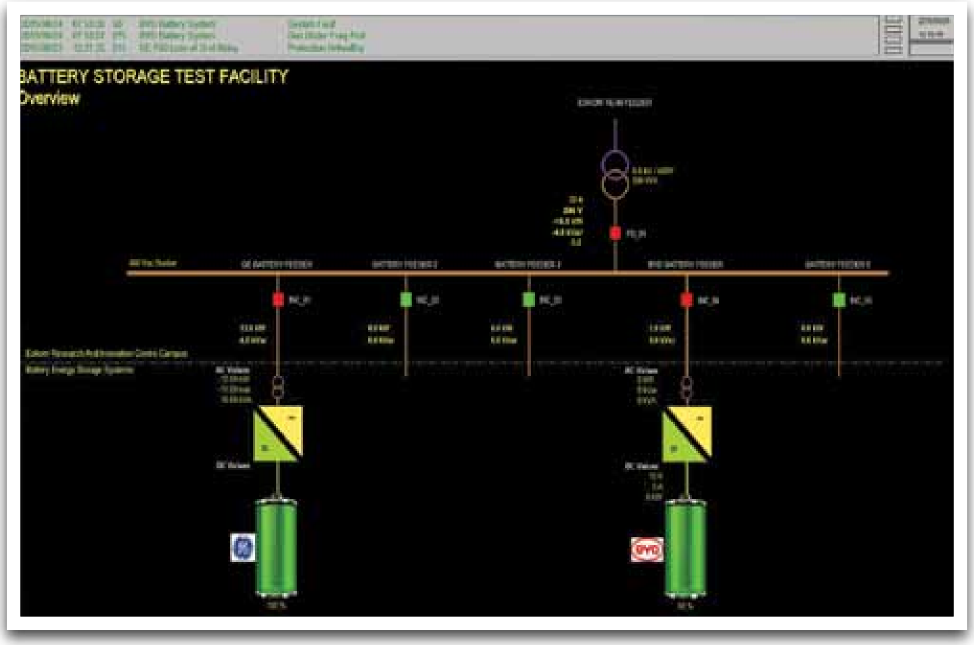



*Fig 5. Desk Top Overview Screen*

## ANALYSIS OF RESULTS

Test 1 successfully demonstrated that load shifting using energy storage can be smoothly achieved and that the Eskom baseload units could be more efficiently operated to minimise costs and emissions, by introducing widespread energy storage. The economic feasibility is still to be determined, based on the future capital costs of such systems and on their lifetime, as demonstrated in the on-going testing.

Test 2 has shown that an energy storage system, combined with a solar system can provide despatchable power, even under the harshest solar performance. The profile replicates (and exaggerates) an intermittently cloudy day with high ramp rates and solar output changing from 100% to 25% in a few seconds. The storage system recognises these changes and compensates for the output, either by providing additional energy to the grid, or by absorbing excess production. Furthermore the storage system absorbs energy during the night time off-peak period, and thereby allows the solar system to provide despatchable energy (at a predetermined level) from 06:30am to 21:00pm.

One drawback of the Test 2 demonstration is that under real conditions the daily "set-point" will need to be determined prior to the day's known solar output. The set-point is the pre-determined level at which the combined system will despatch power into the grid. In the case of Test 2, this was 160kW, based on the total amount of energy produced by the solar system, plus the stored capacity of the storage system, averaged over the defined period. However, under realistic operating conditions, this will require an element of day ahead forecasting to anticipate the solar output for the coming day.

However, the consequences of the day ahead's forecast being wrong are considerably mitigated by the energy storage system. In the event that the forecast is too conservative, the despatchable output will be achieved throughout the day, but the full capacity of the storage system will not need to be used. In the event that the forecast is overly optimistic, the set-point output will be achieved from the start point (06.30 am) to an end point somewhat earlier than desired, based on the total output of the solar system. This endpoint will be determined by when the battery reaches its end of charge state, whereupon the battery will simply stop providing energy until it is allowed to recharge overnight. No damage will be done to the system and hopefully, the 6, or more, hours warning of solar underperformance will allow alternative sources of energy to be activated.

The results of the testing to date have clearly demonstrated:

- Battery energy storage is effective at grid scale.
- It has been possible to test 2 different technologies under directly competitive conditions that replicate the probable operational duty cycles that battery energy storage will be required to perform in South Africa. Further testing will be carried out to establish the longevity of these technologies. Hopefully further technologies will be added to the test programme to fully achieve the original objectives.
- The identification of which technologies are best suited to which applications is an on-going exercise, although the results to date suggest that the one system under test is not suitable for use within Eskom.
- The batteries will need to be used to the end of their useful lives before generic estimates of life can be made. However, indicative performances at the end of the first 3 year test period can be estimated.

# Energy Storage Learnings

*continues from page 19*

- The project has successfully established round trip efficiencies for both of the technologies. These efficiencies differ under different operating cycles. The lithium-ion system has an operating round trip efficiency of between 78 and 81%, whilst the other system is between 65 and 72%.
- It is believed that the lessons learnt during this research project will allow Eskom to go out on commercial tender for energy storage devices and to successfully integrate these devices into the grid.

Whilst further testwork is needed and the incorporation of additional units for comparative testing is necessary, the project has successfully established a valid and respected Test and Demonstration Facility. Furthermore, it has answered, or will answer with further testing, all the original research questions posed at the outset of the project.

This project has highlighted the importance of testing the units under conditions matching the application it is intended for, as flaws and non-performance of the unit can be addressed prior to installation and thus mitigating the risks when installed on site.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the contributions of P. Frampton for the pivotal role he played during the construction of the test facility.

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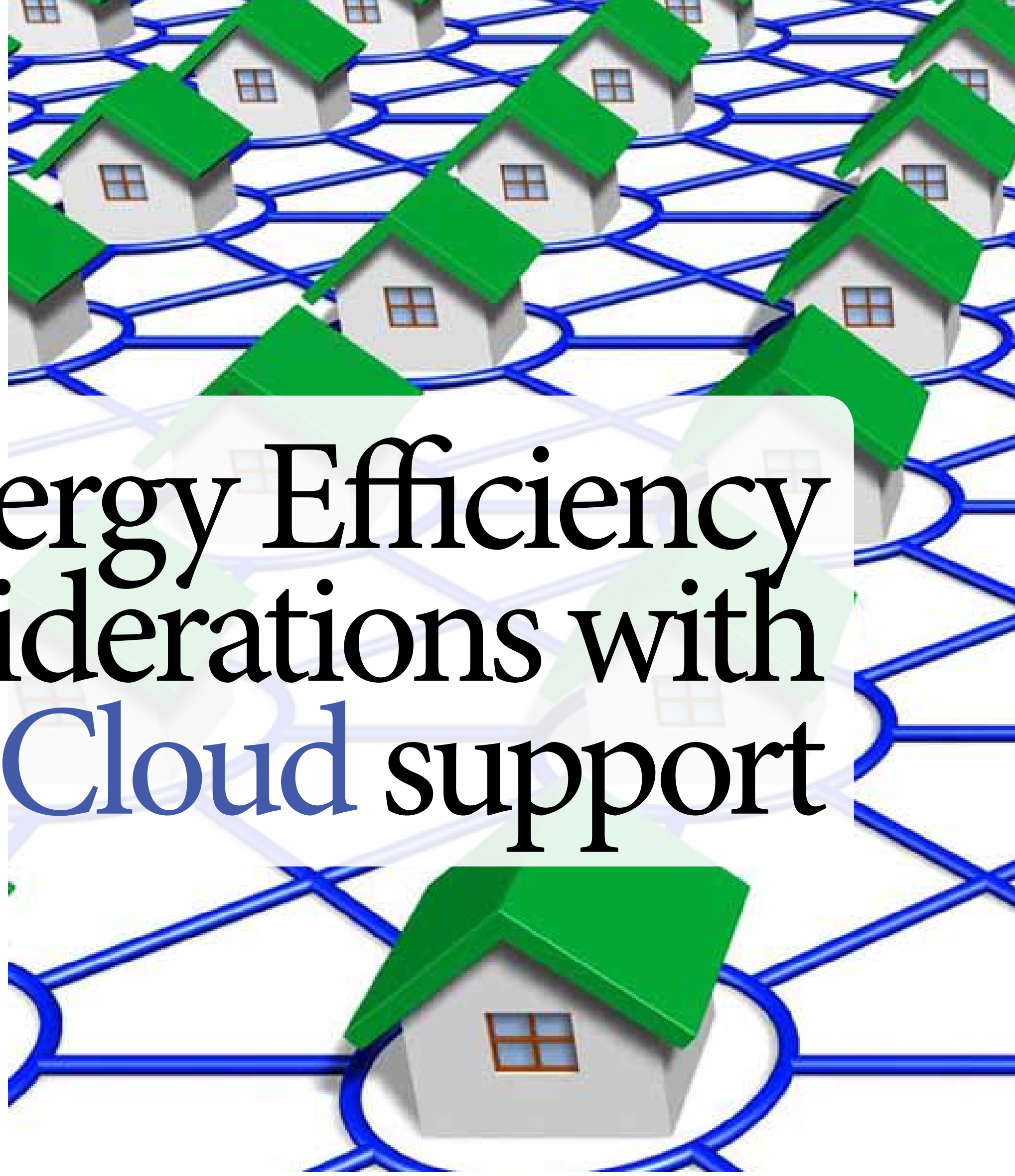

# Energy Efficiency Considerations with Cloud support

**BY |** BAKHE NLEYA **&**
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Ever arising energy demands as well as the associated effects such as adverse climate changes are leading to an increased interest in energy efficiency which by enlarge can only be achieved by the incorporation of Information and Communication Technology (ICT) technologies in legacy and present power grid systems thus transforming them into smart grids.

ICT is responsible for a significant total energy consumption globally and hence the need to implement measures and policies aimed at reducing it. Gradually electrical energy (power) is becoming key to the normal everyday life of humanity as well as for the services provisioned by ICTs.

Smart Grid concepts such as distributed generation, dynamic pricing, and demand/response management, are impacting the operation of ICT services such as, clouds and data centers.

In this paper, we overview smart grid-

driven approaches in energy-efficient communications and data centers and clouds, and the interaction between smart grid and information and communication infrastructures. We provide Smart Grid-driven approaches in energy-efficient communication systems we pay attention to and then we analyze the energy efficiency of an all-optical network support backbone for Smart Grids.

Current and future Smart Grids will incorporate advanced communication, sensing, as well as control capabilities in the power grid's operation, to enhance reliability efficiency, security as well as reduced emissions [1]. Such functionalities/capabilities were limited on legacy grids but, however continued advances in ICT technologies have triggered modernization of both all key elements of the power grid. As such Smart Grids have increased legacy power systems efficiencies by incorporating renewable energy sources in to the grid as well as employing smart demand management and furthermore by adopting measures to curb transmission power losses on the distribution segments of the power grids. lines [1], [2]. Key to all this are energy efficient communications. In terms of communication coverage and functionality, a fully fledged Smart Grid is composed of three domains as follows: Smart Grid Wide Area Network (SG-WAN), Smart Grid Home Area Network (SG-HAN) and a Smart Grid Neighborhood Area Network (SG-NAN) [3].

Typically, a SG-HAN is confined to a single residential house and typically serving a few house-hold smart appliances as well as a smart meter. A SG-NAN houses a few households, all typically fed from the same transformer. SG-WANs interconnect SG-HANs and SG-NANs. The smart meters relay mostly billing data from the residential households using the available Advanced Metering Infrastructure (AMI) and sends it to the utility operator via the SG-NANs. For facilitating monitoring, as well as control of equipment in the field, a separate network known as a Smart Grid Field Area Network (SG-FAN) is created. In practice, the SG-FAN and SG-NAN are quite similar and hence utilize similar communication technologies [4].

The ever-increasing volumes of bandwidth-intensive applications and services are directly driving the requirement for energy efficient enabling networking infrastructures to support the resultant extremely high bandwidths and diverse data

# Energy Efficient Smart Grid

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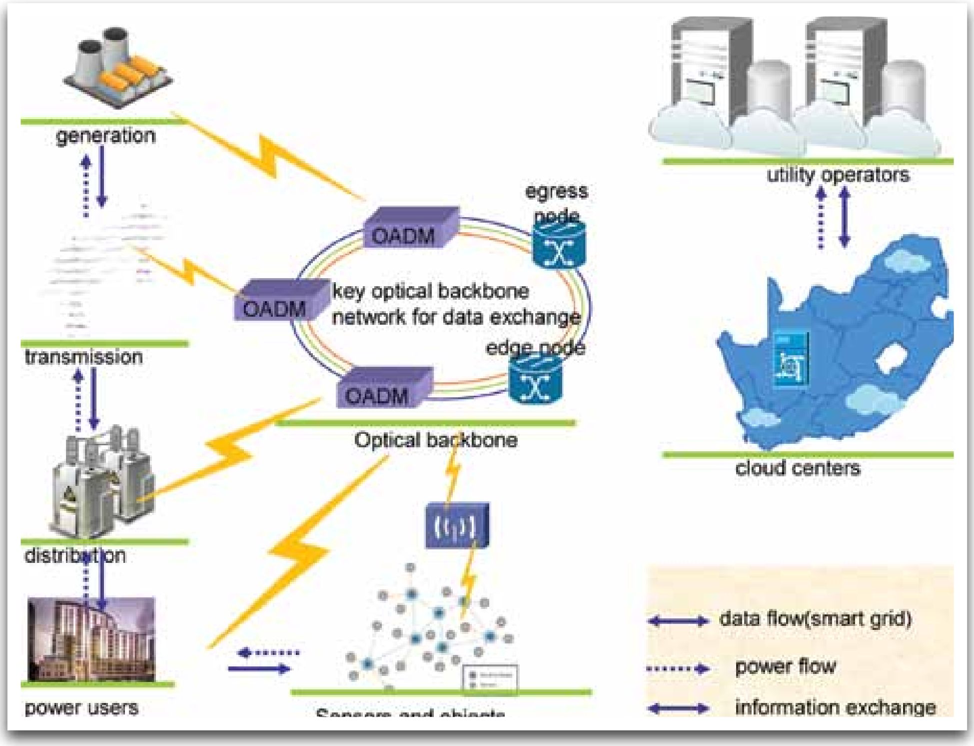



*Figure 1: Smart Grid and support Network infrastructure*

traffic flows. Information infrastructure along with communication infrastructure is a significant consumer of electricity in a smart grid and this attributed to by the presence of cloud com-puting and data centers and hence associated voluminous data exchanges. Sources of this data include [4]:

**INFORMATION SYSTEMS:** utility information systems will generally utilize data from Grid related components such as substations, and consumers to extract critical information about the general state of the distribution network, equipments, energy consumed, the consumption modes, etc. This will be used for improving the design and operation of the grid. Utility information typically includes, Supervisory Control and Data Acquisition (SCADA), Geographic Information System (GIS. Customer Information System (CIS), Advanced Metering Infrastructure (AMI) and Meter Data Management System (MDMS), Demand Response Management System (DRMS) and Outage Management System (OMS.

**ADVANCED METERING INFRASTRUCTURE:** This is a platform for facilitating smart metering.

**SUPERVISORY CONTROL AND DATA ACQUISITION(SCADA):** Its main function is that of acquiring, communicating as well as presentation of data and control information in order to better automation, as well as efficiency. It generally facilitates optimal energy delivery by using programmable controls as well as facilitating, multi-protocol support.

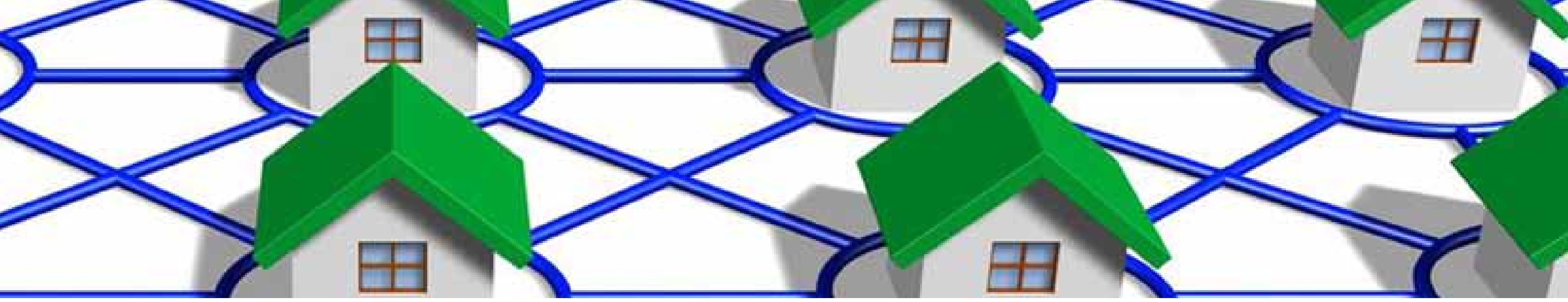
**OUTAGE MANAGEMENT SYSTEM:** These help in enhancing smart grid customers' satisfaction by voluntarily discovering, locating and resolving power outages in a very efficient and short time.

**GEOGRAPHIC INFORMATION SYSTEM(GIS):** The system is primarily for utilities as it visualizing and mapping points of interests in the smart grid. As such it can is a technology aiming at providing the power utility with a global vision of users, generators, power lines position, etc.

**CUSTOMER INFORMATION SYSTEM:** The Customer Information System (CIS) is used to develop the relationship between utilities and customers using every customer interaction. CIS helps utilities to deliver their services efficiently, to automate periodic tasks to understand customers requirements and how each customer is connected to the grid.

**DEMAND RESPONSE MANAGEMENT SYSTEM:** This system brings several benefits such as reduce energy costs, improve stability and security of the smart grid. It gives the utilities the ability to create automated, integrated, and flexible platforms to manage demand response solutions in an efficient and smart manner. The resulting voluminous aggregated data requires a backbone with a matching capacity.

As such, dense wavelength division multiplexed (DWDM) optical backbone networks have enabled increased data transmission capacities to terabits per second ranges, as well as coupling with optical burst switching (OBS) paradigm to address the matching switching capabilities [1]. At transmission level, received data packets are aggregated and assembled into optical burst units generally referred to as data bursts by edge nodes before



| network Domain | device | capacity | power consumption |
|---|---|---|---|
| backbone network | core router | 10Gbps | 25-68.5kW |
| | amplifier | I fiber | 46-106W |
| | regenerator | per lightpath | 6-80W |
| | Converter | per lightpath | 0.5-2W |
| | WDM transponder | 40GBs | 60-100W |
| | OXC | 2-degree | 25-68.5W |
| metro network | Edge switch (router) | 160GBs | 4.21kW |
| | OADM | N/A | 450W |
| | Ethernet switch | 720Gbs | 3.21kW |
| | gateway | 8Gbps | 1.1kW |
| | Edge LAN Switch | 48000Mbps | 100-300W |
| access network | 10/100 Hub | 1200Mbps | 12-35W |
| | WAP | 54Mbps | 8-13W |
| | OLT | 1GBs | 100W |
| | telephony sub switch | 20000 subscribers | 6kW |
| | ONU | 1GBs | 5W |
| household network | modem | up to 300Mbps | 5.7W |
| | router | up to 500Mbps | 5.7W |
| | access point | _ | 1.9W |
| | switch | up to 500Mbs | 2.6W |
| | ONTs | up to 600Mbps | 16.2W |

*Table 1: Power Requirements (Adapted from [4]).*

being transmitted into the core network, thus in the process reducing switching capacity requirements. A powerful driver for this work lies in addressing the power consumption of communication infrastructures in smart grids. The energy bottleneck has long been a key driving force for developing optical interconnects in traditional high-performance computing systems, and is now becoming a limiting factor in telecommunication networks.

Summarily, an OBS backbone network consists of edge and core nodes interconnected via DWDM optical fibre links. It primarily interconnects, residential access, home networks (wired and wireless), core, metro and data centers. Today, most advanced metro core rings consist of Optical Add Drop Multiplexers (OADM) and Optical Cross Connects (OXCs). This survey devotes greater attention to surveying energy efficiency in the backbone as well as its traffic tributaries, mainly the access, and metro networks which when aggregated are expected to surpass the zettabyte threshold soon [2]. Nonetheless, by comparison, the core backbone sections of this supporting network are likely to expend more power than that of the access and metro networks [3].

Presently, residential and metro (wired and wireless) access networks dominate power consumption. However, the high aggregated traffic volumes in the optical backbone network will lead to higher power consumption, thus likely to exceed energy consumption of the access level networks [3], [4].

Our objective in this paper is to provide an overview on energy-efficient techniques employed in present and future optical backbone networks which can sustain ever surging traffic levels with reduced energy consumption. We will generally discuss these mainly under the following general categories namely, designing power efficient end-devices, network redesign i.e. designing power-efficient, traffic engineering, power-aware networking, adaptive operation and energy efficient protection networking.

## ENERGY EFFICIENCT NETWORKING EFFORTS

Due to the purposeful global campaigns aimed at mitigating factors that cause environmental pollution, the ICT/ telecommunication sectors joined the bandwagon in the quest to protect our environment by adopting initiatives that are geared towards energy-efficient communication infrastructures.

In addition, the current departure from the traditional technologies and strategies does not only result in the reduction of harmful gases released into the environment, but also lead to substantially low OPEX for network operators. As previously stated, a significant number of scholars have focused their attention in conducting research in this important niche area to come up with energy-efficient solutions for backbone communication networks.

In this review, we have categorized the main energy-efficient networking techniques used existing in various literatures into five main approaches, namely, network redesign, traffic engineering, power-aware networking, adaptive operation and energy efficiency network protection.

FEATURE

# Energy Efficient Smart Grid

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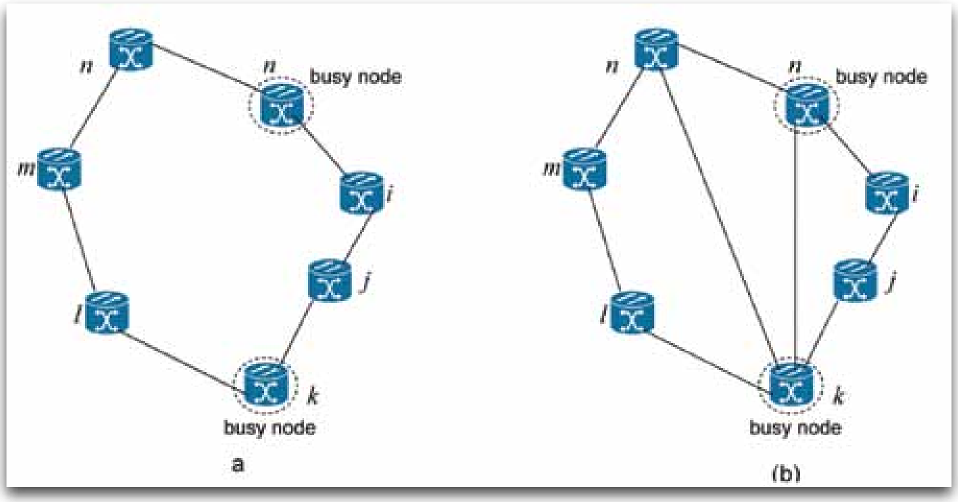



*Figure 2. Networking topologies: (a) ring and (b) mesh [6].*

**A. NETWORK RE-DESIGN**

Generally, the energy usage of the core network can be significantly lowered by redesigning the physical links and the core nodes. Traditionally, the physical links rely on optical technologies, whereas the core nodes have essentially been based on electronic technology [4]. Since electronic devices are slower than their optical components, there is a need to gradually replace most electronic switching components by optical switching devices [4], [5].

Through the technique of "multiple-shelves", the speed of an electronic core router can be improved, but at the expense of increased energy consumption [5]. However, the replacement of a core electronic router by an OXC provides opportunities for very fast switching due to the elimination of bottlenecks that arise due to slow electronic processing. In addition, potential energy savings will be realized as well [5]. Table 1 in the previous section shows some vital information about various core network devices and their respective energy consumptions [4].

By redesigning the physical topology of the core networks via the optimization of available links, massive energy savings may also be realized [4]. Since the CAPEX of an optical core network is mainly determined by link deployment costs, it is therefore prudent and logical to interconnect core nodes through as fewer number of links as is possible. However, it is crucial to strike a balance between the number of links, performance (reliability) as well as and energy consumption as some topologies may contain fewer links but end up consuming significantly large amounts of energy and at the same time degrading reliability.

Figure 2 illustrates two different topologies designed to reduce cost and energy consumption respectively, but at the same time maintaining reliability.

The topology in (a) costs less as it has relatively fewer links. However, the topology consumes more power as communication between selected nodes involves many links. Overall it follows that optimizing the physical topology is critical in balancing power consumption at reduced levels, cost as well as reliability, and as such an optimized network topology accommodates traffic using fewer network devices.

**TRAFFIC ENGINEERING**

Another way of reducing energy consumption of core networks is to limit the use of network devices such as ports and fibres, by utilizing traffic grooming techniques [7], [8]. If several low-granularity traffic movement is aggregated into a few, high-granularity traffic flow, the number of wavelengths that traverse the core network will be drastically reduced and this leads to a reduction in demand of network resources [7], [9].

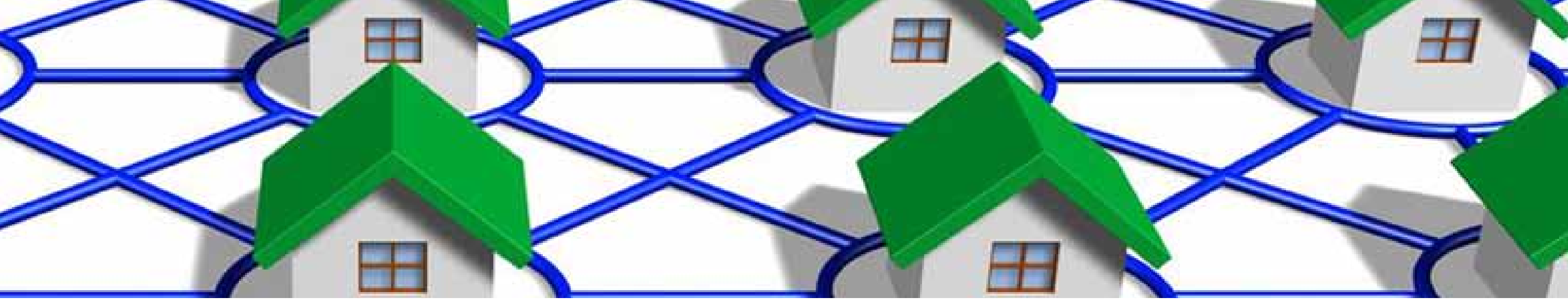
**ENERGY-AWARE NETWORKING**

In general, network elements in core networks are configured to support peak-period traffic and thus during off-peak periods, significant amounts of energy are unwisely wasted since most devices will not be performing any functions [8], [9], [10].

Due to the increased sizes of current networks, and hence several energy consuming devices, it has become very critical and important to switch off some devices during low traffic periods, and this in turn calls for the adjustment of routing schemes to be fully optimized to become energy-efficient.

**LOAD-ADAPTIVE OPERATION**

Previous studies on the rated power consumption values of network devices in [7] suggest that low capacity devices (or devices running at low operational speeds) expend less power. However, high-capacity devices consume less power per bit of transmitted traffic and, thus, are



more energy efficient [7]. To attain higher energy efficiency, or rather low-power consumption, it is preferable to deploy a minimum number of network devices with capacity that matches the actual traffic speed.

## CONCLUSIONS

Globally ICTs are significant energy consumer as well as Greenhouse Gas (GHG) emitter. The cloud and data centres expend large energy volumes such that consequently, their OPEX is also surging with increasing electricity tariffs and associated carbon emission taxes.

This has prompted research into techniques that enhance energy efficiency of ICTs. Applying existing smart grid-driven techniques together with traditional ones can lead to OPEX reductions. Measures such as distributed generation, dynamic pricing schemes, demand management, monitoring of faults and disturbances can be effectively utilized to minimize both energy consumption and losses and consequently emissions of ICTs.

In this survey paper, we have surveyed techniques employed in present and future optical backbone networks which can sustain ever surging traffic levels with reduced energy consumption.

Focusing more attention to green data centres and clouds (i.e. repositories for the storage, management, and dissemination of data in which the mechanical, lighting, electrical and computer systems are designed for maximum energy efficiency and minimum environmental impact) is required. Well known techniques and measures include: such as usage of alternative energy technologies (photovoltaics, heat pumps, and evaporative cooling); minimization of footprints of the buildings; usage of low-emission building materials, carpets and paints; waste recycling; Installation of catalytic converters on backup generators; sustainable landscaping; usage of hybrid or electric company vehicles.

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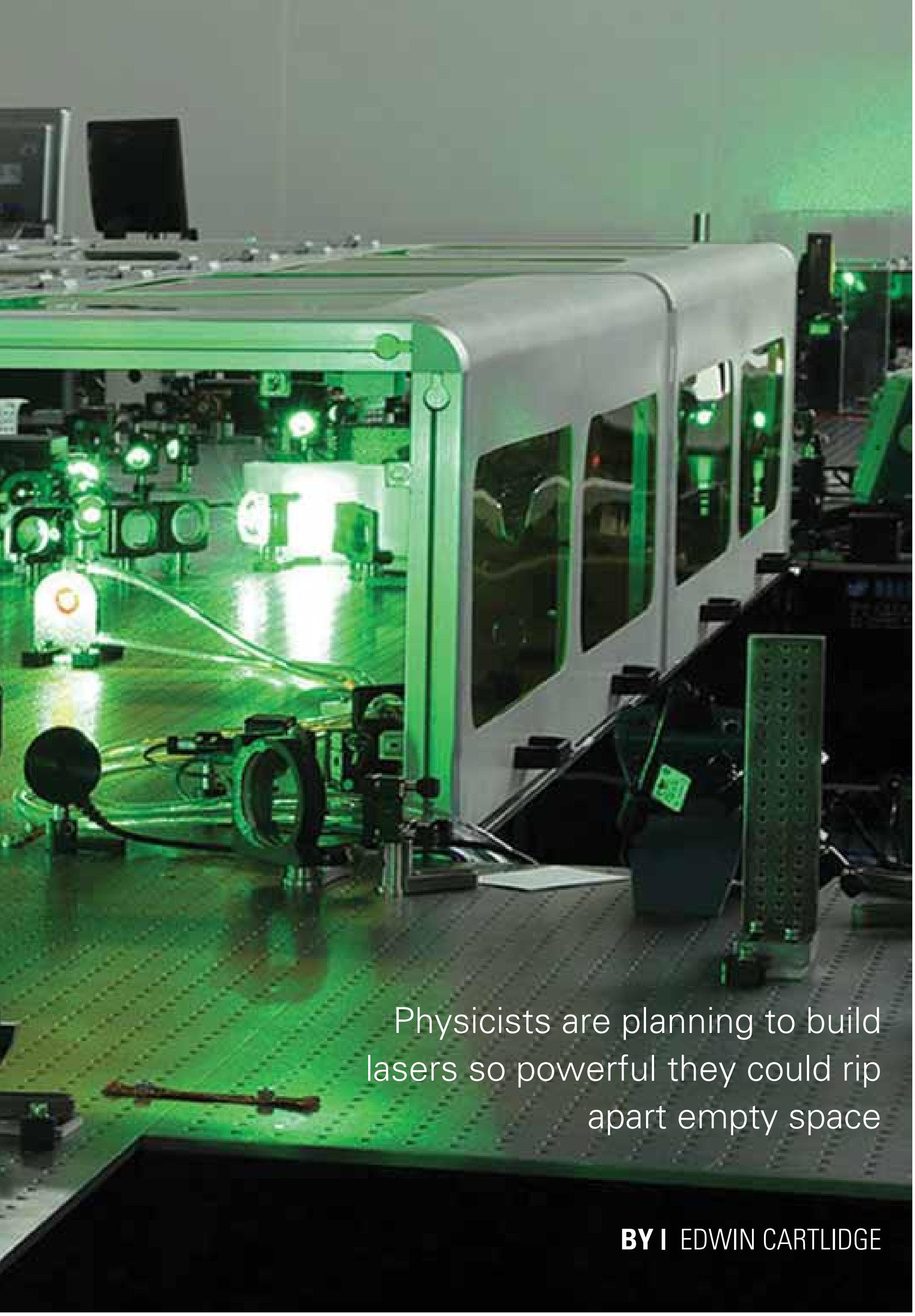
# Chinese laser sets power records

Inside a cramped laboratory in Shanghai, China, physicist Ruxin Li and colleagues are breaking records with the most powerful pulses of light the world has ever seen. At the heart of their laser, called the Shanghai Superintense Ultrafast Laser Facility (SULF), is a single cylinder of titanium-doped sapphire about the width of a Frisbee. After kindling light in the crystal and shunting it through a system of lenses and mirrors, the SULF distills it into pulses of mind-boggling power. In 2016, it achieved an unprecedented 5.3 million billion watts, or petawatts (PW). The lights in Shanghai do not dim each time the laser fires, however. Although the pulses are extraordinarily powerful, they are also infinitesimally brief, lasting less than a trillionth of a second. The researchers are now upgrading their laser and hope to beat their own record by the end of this year with a 10-PW shot, which would pack more than 1000 times the power of all the world's electrical grids combined.

The group's ambitions don't end there. This year, Li and colleagues intend to start building a 100 PW laser known as the Station of Extreme Light (SEL). By 2023, it could be flinging pulses into a chamber 20 metres underground, subjecting targets to extremes of temperature and pressure not normally found on Earth, a boon to astrophysicists and materials scientists alike. The laser could also power demonstrations of a new way to accelerate particles for use in medicine and high-energy physics. But



## Physicists are planning to build lasers so powerful they could rip apart empty space

**BY |** EDWIN CARTLIDGE

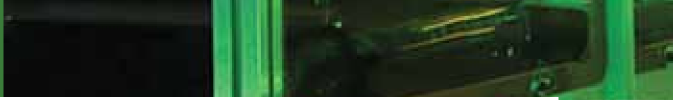
most alluring, Li says, would be showing that light could tear electrons and their antimatter counterparts, positrons, from empty space - a phenomenon known as "breaking the vacuum." It would be a striking illustration that matter and energy are interchangeable, as Albert Einstein's famous $E=mc^2$ equation states. Although nuclear weapons attest to the conversion of matter into immense amounts of heat and light, doing the reverse is not so easy. But Li says the SEL is up to the task. *"That would be very exciting,"* he says. *"It would mean you could generate something from nothing."*

The Chinese group is *"definitely leading the way"* to 100 PW, says Philip Bucksbaum, an atomic physicist at Stanford University in Palo Alto, California. But there is plenty of competition. In the next few years, 10 PW devices should switch on in Romania and the Czech Republic as part of Europe's Extreme Light Infrastructure, although the project recently put off its goal of building a 100 PW-scale device. Physicists in Russia have drawn up a design for a 180-PW laser known as the Exawatt Center for Extreme Light Studies (XCELS), while Japanese researchers have put forward proposals for a 30-PW device.

Largely missing from the fray are U.S. scientists, who have fallen behind in the race to high powers, according to a study published last month by a National Academies of Sciences, Engineering, and Medicine group that was chaired by Bucksbaum. The study calls on the Department of Energy to plan for at least one high-power laser facility, and that gives hope to researchers at the University of Rochester in New York, who are developing plans for a 75 PW laser, the Optical Parametric Amplifier Line (OPAL). It would take advantage of beamlines at OMEGA-EP, one of the country's most powerful lasers. *"The [Academies] report is encouraging,"* says Jonathan Zuegel, who heads the OPAL.

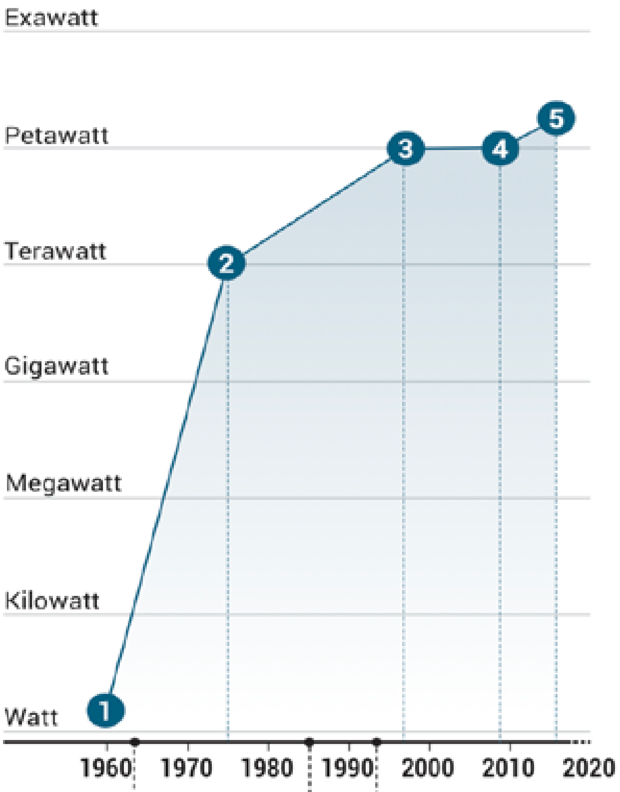
Invented in 1960, lasers use an external "pump," such as a flash lamp, to excite electrons within the atoms of a lasing material - usually a gas, crystal, or semiconductor. When one of these excited electrons falls back to its original state it emits a photon, which in turn stimulates another electron to emit a photon, and so on. Unlike the spreading beams of a flashlight, the photons in a laser emerge in a tightly packed stream at specific wavelengths.

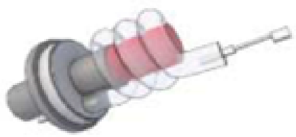
Because power equals energy divided by time, there are basically two ways to maximize it: either boost the energy of your laser, or shorten the duration of its pulses. In the 1970s, researchers at Lawrence Livermore National Laboratory (LLNL) in California focused on the former, boosting



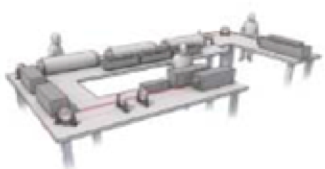
# Powering up

Researchers at Lawrence Livermore National Laboratory (LLNL) in Livermore, California, set early power records by amplifying energies in mammoth machines. But a room-size laser in Shanghai, China, now holds the record, after squeezing modest energies into extremely short bursts. Three important techniques have propelled lasers to high powers.



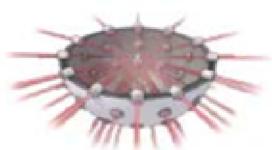



**1 First laser**
Theodore Maiman coaxed laser light from a 2-centimeter-long ruby crystal pumped by photo graphic flash lamps.

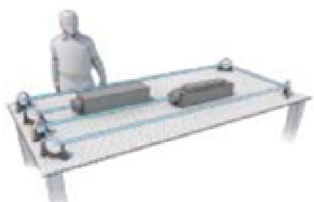


**2 Janus (LLNL)**
The two-beam laser amplified 100-picoseconc pulses to 100 joules of energy to create the first terawatt shot.

**3 Nova (LLNL)**
Pulses from the Nova laser were shortened using CPA to achieve the first petawatt.



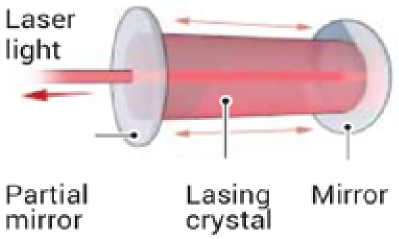
**4 National Ignition Facility (LLNL)**
Shots focus 192 high-energy pulses on a target to induce fusion. Because the pulses are long, their power does not exceed a petawatt.



**5 Shanghai Superintense Ultra fast Laser Facility**
By squeezing laser pulses to just tens of femtoseconds, the laboratory achieved record powers with tabletop systems.

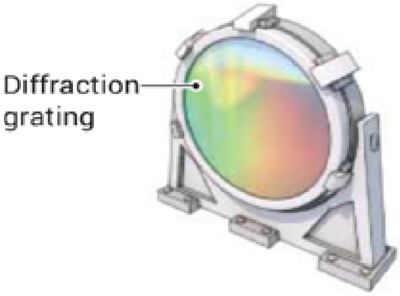
### Mode locking

Although very pure, laser light is emitted over a range of wave lengths, or modes, that resonate in cavities like guitar strings. These modes can be made to constructively interfere for an intense burst tens of femtoseconds long.



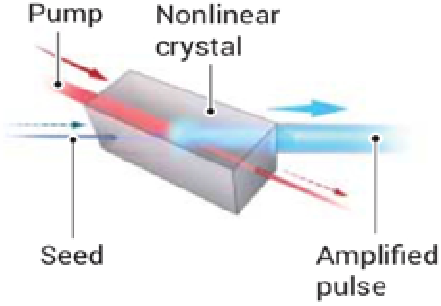

### Chirped-pulse amplification (CPA)

Intense pulses can damage amplifiers. CPA avoids that by stretching a laser pulse with diffraction gratings. After safe amplification, the pulse is compressed.




### Optical parametric amplification

A high-energy pump beam can amplify a stretched seed pulse within a nonlinear crystal that can be made large to withstand intense inputs.



laser energy by routing beams through additional lasing crystals made of glass doped with neodymium. Beams above a certain intensity, however, can damage the amplifiers. To avoid this, LLNL had to make the amplifiers ever larger, many tens of centimetres in diameter. But in 1983, Gerard Mourou, now at the École Polytechnique near Paris, and his colleagues made a breakthrough. He realized that a short laser pulse could be stretched in time - thereby making it less intense - by a diffraction grating that spreads the pulse into its component colors. After being safely amplified to higher energies, the light could be recompressed with a second grating. The end result: a more powerful pulse and an intact amplifier.

This "chirped-pulse amplification" has become a staple of high-power lasers. In 1996, it enabled LLNL researchers to generate the world's first petawatt pulse with the Nova laser. Since then, LLNL has pushed to higher energies in pursuit of laser-driven fusion. The lab's National Ignition Facility (NIF) creates pulses with a mammoth 1.8 megajoules of energy in an effort to heat tiny capsules of hydrogen to fusion temperatures. However, those pulses are comparatively long and they still generate only about 1 PW of power.

To get to higher powers, scientists have turned to the time domain: packing the energy of a pulse into ever-shorter durations. One approach is to amplify the light in titanium-doped sapphire crystals, which produce light with a large spread of frequencies. In a mirrored laser chamber, those pulses bounce back and forth, and the individual frequency components can be made to cancel each other out over most of their pulse length, while reinforcing each other in a fleeting pulse just a few tens of femtoseconds long. Pump those pulses with a few hundred joules of energy and you get 10 PW of peak power. That's how the SULF and other sapphire-based lasers can break power records with equipment that fits in a large room and costs just tens of millions of dollars, whereas NIF costs $3.5 billion and needs a building 10 stories high that covers the area of three U.S. football fields.

Raising pulse power by another order of magnitude, from 10 PW to 100 PW, will require more wizardry. One approach is to boost the energy of the pulse from hundreds to thousands of joules. But titanium-sapphire lasers struggle to achieve those energies because the big crystals needed for damage-free amplification tend to lase at right angles to the beam—thereby sapping energy from the pulses. So scientists at the SEL, XCELS, and OPAL are pinning their hopes on what are known as optical parametric amplifiers. These take a pulse stretched out by an optical grating and send it into an artificial "nonlinear" crystal, in which the energy of a second, "pump" beam can be channeled into the pulse. Recompressing the resulting high-energy pulse raises its power.

To approach 100 PW, one option is to combine several such pulses - four 30 PW pulses in the case of the SEL and a dozen 15 PW pulses at the XCELS. But precisely overlapping pulses just tens of femtoseconds long will be "very, very difficult," says LLNL laser physicist Constantin Haefner. They could be thrown off course by even the smallest vibration or change in temperature, he argues. The OPAL, in contrast, will attempt to generate 75 PW using a single beam.

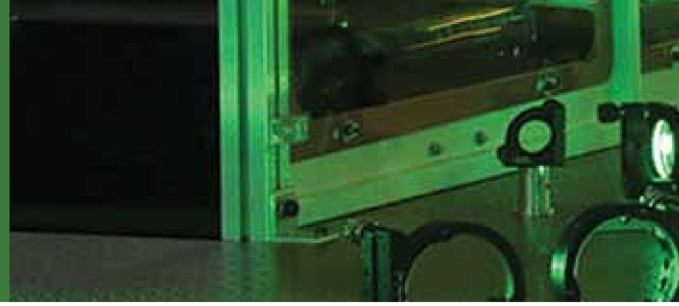
Mourou envisions a different route to 100 PW: adding a second round of pulse compression. He proposes using thin plastic films to broaden the spectrum of 10 PW laser pulses, then squeezing the pulses to as little as a couple of femtoseconds to boost their power to about 100 PW.

Once the laser builders summon the power, another challenge will loom: bringing the beams to a singularly tight focus. Many scientists care more about intensity—the power per unit area—than the total number of petawatts. Achieve a sharper focus, and the intensity goes up. If a 100 PW pulse can be focused to a spot measuring just 3 micrometres across, as Li is planning for the SEL, the intensity in that tiny area will be an astonishing $10^{24}$ watts per square centimeter ($W/cm^2$) - some 25 orders of magnitude, or 10 trillion trillion times, more intense than the sunlight striking Earth.

Those intensities will open the possibility of breaking the vacuum. According to the theory of quantum electrodynamics (QED), which describes how electromagnetic fields interact with matter, the vacuum is not as empty as classical physics would have us believe. Over extremely short time scales, pairs of electrons and positrons, their antimatter counterparts, flicker into existence, born of quantum mechanical uncertainty. Because of their mutual attraction, they annihilate each another almost as soon as they form.

But a very intense laser could, in principle, separate the particles before they collide. Like any electromagnetic wave, a laser beam contains an electric field that whips back and forth. As the beam's intensity rises, so, too, does the strength of its electric field.

FEATURE



# Chinese laser

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*Amplifiers for the University of Rochester's OMEGA-EP, lit up by flash lamps, could drive a U.S. high-power laser.*

At intensities around $10^{24}$ W/$cm^2$, the field would be strong enough to start to break the mutual attraction between some of the electron-positron pairs, says Alexander Sergeev, former director of the Russian Academy of Sciences's (RAS's) Institute of Applied Physics (IAP) in Nizhny Novgorod and now president of RAS. The laser field would then shake the particles, causing them to emit electromagnetic waves - in this case, gamma rays. The gamma rays would, in turn, generate new electron-positron pairs, and so on, resulting in an avalanche of particles and radiation that could be detected. *"This will be completely new physics,"* Sergeev says. He adds that the gamma ray photons would be energetic enough to push atomic nuclei into excited states, ushering in a new branch of physics known as "nuclear photonics" - the use of intense light to control nuclear processes.

One way to break the vacuum would be to simply focus a single laser beam onto an empty spot inside a vacuum chamber. But colliding two beams makes it easier, because this jacks up the momentum needed to generate the mass for electrons and positrons. The SEL would collide photons indirectly. First, the pulses would eject electrons from a helium gas target. Other photons from the laser beam would ricochet off the electrons and be boosted into high-energy gamma rays. Some of these in turn would collide with optical photons from the beam.

Documenting these head-on photon collisions would itself be a major scientific achievement. Whereas classical physics insists that two light beams will pass right through each other untouched, some of the earliest predictions of QED stipulate that converging photons occasionally scatter off one another. *"The predictions go back to the early 1930s,"* says Tom Heinzl, a theoretical physicist at Plymouth University in the United Kingdom. *"It would be good if we could confirm them experimentally."*

Besides making lasers more powerful, researchers also want to make them shoot faster. The flash lamps that pump the initial energy into many lasers must be cooled for minutes or hours between shots, making it hard to carry out research that relies on plenty of data, such as investigating whether, very occasionally, photons transform into particles of the mysterious dark matter thought to make up much of the universe's mass. *"Chances are you would need a lot of shots to see that,"* says Manuel Hegelich, a physicist at the University of Texas in Austin.

A higher repetition rate is also key to using a high-power laser to drive beams of particles. In one scheme, an intense beam would transform a metal target into a plasma, liberating electrons that, in turn, would eject protons from nuclei on the metal's surface. Doctors could use those proton pulses to destroy cancers—and a higher firing rate would make it easier to administer the treatment in small, individual doses.

Physicists, for their part, dream of particle accelerators powered by rapid-fire laser pulses. When an intense laser pulse strikes a plasma of electrons and positive ions, it shoves the lighter electrons forward, separating the charges and creating a secondary electric field that pulls the ions along behind the light like water in the wake of a speedboat. This "laser wakefield acceleration" can accelerate charged particles to high energies in the space of a millimetre or two, compared with many metres for conventional accelerators. Electrons thus accelerated could be wiggled by magnets to create a so-called free-electron laser (FEL), which generates exceptionally bright and brief flashes of x-rays that can illuminate short-lived chemical and biological phenomena. A laser-powered FEL could be far more compact and cheaper than those powered by conventional accelerators.

In the long term, electrons accelerated by high-repetition PW pulses could slash the cost of particle physicists' dream machine: a 30-kilometre-long electron-positron collider that would be a successor to the Large Hadron Collider at CERN, the European particle physics laboratory near Geneva, Switzerland. A device based on a 100 PW laser could be at least 10 times shorter and cheaper than the roughly $10 billion machine now envisaged.

Both the linear collider and rapid-fire FELs would need thousands, if not millions, of shots per second, well beyond current technology. One possibility, being investigated by Mourou and colleagues, is to try to combine the output of thousands of quick-firing fiber amplifiers, which don't need to be pumped with flash tubes. Another option is to replace the flash tubes with diode lasers, which are expensive, but could get cheaper with mass production.

For the moment, however, Li's group in China and its U.S. and Russian counterparts are concentrating on power. Efim Khazanov, a laser physicist at IAP, says the XCELS could be up and running by about 2026 - assuming the government agrees to the cost: roughly 12 billion rubles (about $200 million). The OPAL, meanwhile, would be a relative bargain at between $50 million and $100 million, Zuegel says.

But the first laser to rip open the vacuum is likely to be the SEL, in China. An international committee of scientists last July described the laser's conceptual design as "unambiguous and convincing," and Li hopes to get government approval for funding - about $100 million - early this year. Li says other countries need not feel left in the shadows as the world's most powerful laser turns on, because the SEL will operate as an international user facility.

Zuegel says he doesn't "like being second," but acknowledges that the Chinese group is in a strong position. *"China has plenty of bucks,"* he says. *"And it has a lot of really smart people. It is still catching up on a lot of the technology, but it's catching up fast."* **wn**

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ALL-SECTOR ENERGY ROADMAPS FOR 139 COUNTRIES OF THE WORLD

# 100% Clean and Renewable Wind, Water, and Sunlight

For the world to reverse global warming, eliminate millions of annual air-pollution deaths, and provide secure energy, every country must have an energy roadmap based on widely available, reliable, zero-emission energy technologies. This study presents such roadmaps for 139 countries of the world. These roadmaps are far more aggressive than what the Paris agreement calls for, but are still technically and economically feasible.

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The solution is to electrify all energy sectors (transportation, heating/cooling, industry, agriculture/forestry/fishing) and provide all electricity with 100% wind, water, and solar (WWS) power. If fully implemented by 2050, the roadmaps will enable the world to avoid 1.5°C global warming and millions of annual air-pollution deaths, create 24.3 million net new long-term, full-time jobs, reduce energy costs to society, reduce energy end-use by 42.5%, reduce power disruption, and increase worldwide access to energy.

The seriousness of air-pollution, climate, and energy-security problems worldwide requires a massive, virtually immediate transformation of the world's energy infrastructure to 100%

clean, renewable energy producing zero emissions. For example, each year, 4-7 million people die prematurely and hundreds of millions more become ill from air pollution,[1,2] causing a massive amount of pain and suffering that can nearly be eliminated by a zero-emission energy system. Similarly, avoiding 1.5˚C warming since preindustrial times requires no less than an 80% conversion of the energy infrastructure to zero-emitting energy by 2030 and 100% by 2050. Lastly, as fossil-fuel supplies dwindle and their prices rise, economic, social, and political instability may ensue unless a replacement energy infrastructure is developed well ahead of time.

# 100% Clean Energy

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As a response to these concerns, this study provides roadmaps for 139 countries for which raw energy data are available.[3] The roadmaps describe a future where all energy sectors are electrified or use heat directly with existing technology, energy demand is lower due to several factors, and the electricity is generated with 100% wind, water, and sunlight (WWS). The roadmaps are not a prediction of what might happen. They are one proposal for an end-state mix of WWS generators by country and a timeline to get there that we believe can largely solve the world's climate-change, air-pollution, and energy-security problems. However, the mixes we propose are not unique, because many combinations of WWS generators can result in stable, low-cost systems of energy production, distribution, storage, and use.[4]

Previous studies have established that it may be technically and economically feasible to transition the world as a whole[5,6] and the 50 US states[7] to 100% WWS for all purposes, and that the main barriers are social and political. Other studies (e.g., for the UK,[8] Europe and North Africa,[9] Australia,[10,11] Europe,[12,13] Great Britain,[14] Hungary,[15] Ireland,[16] UK,[17] Denmark,[18] France,[19] several world regions,[20] and 16 countries[21]) have looked at similar issues, but for individual countries or regions, selected sectors, partial carbon emission reductions, or carbon emission reductions only rather than air pollutant as well as carbon emission reductions.

This study uses a unified methodology to examine the question of whether it is economically possible, with mainly existing technologies and only a few developing technologies, to transition 139 countries to 100% WWS in all energy sectors, thereby eliminating the maximum possible air pollution and greenhouse-gas emissions in those countries.

More specifically, we estimate the 2050 annually averaged power demand for 139 countries before and after all energy sectors have been electrified. We then perform a renewable resource analysis with multiple datasets in each country and use it to help determine one of many possible mixes of clean, renewable generators that can satisfy the annual demand. The generators are almost all commercially available solar, wind, hydropower, and geothermal technologies, except that we assume that two technologies not yet widely used, tidal and wave power, are installed in small amounts in a few countries. Similarly, most of the electric technologies that we propose for replacing fossil-fuel technologies are already commercial on a large scale today (e.g., electric heat pumps for air and water heating, induction cooktops, electric passenger vehicles, electric induction furnaces, electric arc furnaces, dielectric heaters), but a few are still being designed for commercial use (e.g., electric aircraft and hybrid hydrogen fuel cell-electric aircraft). We then draw on a previous analysis to estimate the additional energy-storage capacity needed for balancing time-dependent supply and demand during a year. The present study does not examine grid stability, since it is evaluated in separate work.

Finally, we estimate the land and ocean footprint and spacing areas required for the WWS scenario plus the energy costs, air-pollution damage costs, climate costs, and job creation/loss for the WWS versus BAU scenarios. With this information, we evaluate whether each country can technically (with the country's available renewable resources and with existing plus developing technologies) and economically meet annual average power demand while providing environmental benefits and jobs.

In summary, each 100% WWS roadmap developed here provides an example of what a 2050, 100% WWS versus BAU all-sector energy infrastructure can look like in terms of:

1. Future end-use demand (load) in each energy sector in the WWS and BAU cases;
2. Numbers of WWS generators needed and their footprint and spacing areas;
3. WWS raw resources and potential, including solar photovoltaic (PV) rooftop potential;
4. Costs of energy, transmission, and distribution in the BAU and WWS cases;
5. Air-pollution mortality and morbidity avoided and their costs due to WWS;
6. Carbon emissions avoided and global-warming costs due to WWS;
7. Changes in job numbers and earnings due to WWS; and
8. Policy measures to implement the roadmaps and a transition timeline.

While some suggest that energy options aside from WWS, such as nuclear power, coal with carbon capture and sequestration (coal-CCS), biofuels, and bioenergy, can play major roles in solving these problems, all four of those technologies may represent opportunity costs in terms of carbon and health-affecting air-pollution emissions.[5,22]

Nuclear and coal-CCS may also represent opportunity costs in terms of their direct energy costs and in terms of their time lag between planning and oper- ation relative to WWS.[5,22-25]

| Scenario | Total End-Use Load (GW) | Residential % of Total | Commercial % of Total | Industrial % of Total | Transport % of Total | Ag/ Forestry/ Fishing % of Total | Other % of Total | (a) 2050 Change in Load (%) due to Higher Work: Energy Ratio of WWS | (b) 2050 Change in Load (%) due to Eliminating Upstream w/WWS | (c) 2050 Change in Load (%) due to Efficiency Beyond BAU w/WWS | Total 2050 Change in Load (%) w/WWS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BAU 2012 | 12,100 | 22.4 | 8.10 | 38.7 | 27.4 | 2.13 | 1.37 | | | | |
| BAU 2050 | 20,600 | 20.4 | 8.08 | 37.3 | 31.0 | 1.87 | 1.34 | | | | |
| WWS 2050 | 11,800 | 25.7 | 11.2 | 42.1 | 16.0 | 2.85 | 2.15 | −23.0 | −12.7 | −6.89 | −42.5 |

*Table 1. 2012 BAU, 2050 BAU, and 2050 100% WWS End-Use Loads (GW) by Sector, Summed Among 139 Countries*

The last column shows the total percent reduction in 2050 BAU end-use load due to switching to WWS, including the effects of reduced energy use due to;
a. the higher work to energy ratio of electricity over combustion,
b. eliminating energy industry self-use for the upstream mining, transporting, and/or refining of coal, oil, gas, biofuels, bioenergy, and uranium, and
c. assumed policy-driven increases in end-use energy efficiency beyond those in the BAU case.

Moreover, the Intergovernmental Panel on Climate Change concludes that there is “robust evidence” and “high agreement” that “Barriers to and risks associated with an increasing use of nuclear energy include operational risks and the associated safety concerns, uranium mining risks, financial and regulatory risks, unresolved waste management issues, nuclear weapons proliferation concerns, and adverse public opinion.” As such, expanding the use of nuclear to countries where it does not exist may increase weapons proliferation and meltdown risks. More advanced nuclear cannot be evaluated fully until it is commercialized but will likely have some if not several of the issues associated with current nuclear, including waste storage and disposal, accident risks, and weapons proliferation risks. There is no known way at this time to eliminate these risks.

By contrast, WWS technologies have none of these risks. Thus, we are proposing and evaluating a system that we believe provides the greatest environmental benefits with the least risk.

Even though tidal and wave power are not widely used, they have been used for power generation in the open ocean for years, have been evaluated to be clean and to present no health risk to humans, and produce power with less time variation than offshore wind so would complement the other resources proposed here if they can be scaled up. Similarly, electric and hydrogen fuel cell hybrid commercial aircraft technologies already exist in small prototypes and in passenger cars, and we do not propose their full development until 2035–2040, whereas we need clean electric power resources starting today. In summary, we focus on WWS technologies, which at least appear possible to solve critical environmental problems in a timely manner. Whether the roadmaps are implemented rapidly, however, depends on social and political factors.

## DEMAND REDUCTION UPON CONVERSION TO WWS

Tables 1 provide one possible scenario of 139-country BAU and WWS end-use power demand (load) in 2050. End-use load is the power in delivered electricity or fuel that is actually used to provide services such as heating, cooling, lighting, and transportation. It excludes losses during electricity or fuel production and transmission but includes industry self-energy-use for mining, transporting, and refining fossil fuels. All end users that can be electrified use WWS power directly; however, some transportation uses hydrogen produced from WWS electricity.

In 2012, the 139-country all-purpose, end-use load was $12.1 TW. Of this, 2.4 TW (19.6%) was electricity demand. Under BAU, all-purpose end-use load may grow to 20.6 TW in 2050. Transitioning to 100% WWS by 2050 reduces the 139-country load by $42.5%, to 11.8 TW (Table 1), with the greatest percentage reduction in transportation. While electricity use increases with WWS, conventional fuel use decreases to zero. The increase in electric energy is much less than the decrease in energy in the gas, liquid, and solid fuels that the electricity replaces for three major reasons:

# 100% Clean Energy

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1. The higher energy-to-work conversion efficiency of using electricity for heating, heat pumps, and electric motors, and using electrolytic hydrogen in hydrogen fuel cells for transportation, compared with using fossil fuels;
2. The elimination of energy needed to mine, transport, and refine coal, oil, gas, biofuels, bioenergy, and uranium;
3. Assumed modest additional policy-driven energy-efficiency measures beyond those under BAU.

These factors decrease average demand $23.0%, 12.6%, and 6.9%, respectively, for a total of 42.5%. Thus, WWS not only replaces fossil-fuel electricity directly but is also an energy-efficiency measure, reducing demand.

## NUMBERS OF ELECTRIC POWER GENERATORS, LAND REQUIRED, AND RESOURCES AVAILABLE

Table 2 summarizes the numbers of WWS generators needed to power all 139 countries in 2050 for all energy purposes assuming the end-use loads by country and the percent of each country's load met by each generator. The numbers of generators were derived accounting for power loss during transmission, distribution, and generator maintenance; and competition among wind turbines for limited kinetic energy (array losses). The numbers also assume all power for a country is generated and used in the country in the annual average, and thus ignore cross-border transfers of energy that will occur in reality.

Rooftop PV will go on rooftops or elevated canopies above parking lots, highways, and structures without requiring additional land. In 2050, residential rooftops (including garages and carports) among the 139 countries may support up to 26.6 $TW_{dc\text{-}peak}$ of installed power, of which 34.9% is proposed for use. Commercial/government rooftops (including parking lots and parking structures) may support 11.1 $TW_{dc\text{-}peak}$, of which 68.2% is proposed for use. Low-latitude and high GDP per-capita countries are hypothesized to adopt proportionately more PV than high-latitude, low GDP-per-capita countries. While utility-scale PV can operate in any country, because it can use direct and diffuse sunlight, CSP is viable only where significant direct sunlight exists. Thus, CSP penetration in several countries is limited.

Onshore wind is available in every country but assumed to be deployed aggressively primarily in countries with good wind resources and sufficient land. Offshore wind is assumed viable in the 108 out of 139 countries with ocean or lake coastline. In most of these countries, the technical potential installed capacity is determined from the area of coastal water less than 60m depth and with a capacity factor of at least 34% in the annual average.

The 2050 nameplate capacity of hydropower is assumed to be the same as in 2015. However, existing hydropower is assumed to run at slightly higher capacity factor. This assumption is justified by the fact that in many places, hydropower use is currently suppressed by the availability and use of gas and coal, which will be eliminated here. If current capacity factors are limited by low rainfall, it may also be possible to make up for the deficit with additional run-of-the-river hydro, pumped hydro, or non-hydro WWS energy sources. Geothermal, tidal, and wave power are limited by each country's technical potentials.

Table 2 also lists needed installed capacities of additional CSP with storage, new solar thermal collectors, and existing geothermal heat installations. These collectors are needed to provide electricity or heat that is mostly stored for peaking power.

Table 2 indicates that 4.26% of the 2050 nameplate capacity required for a 100% all-purpose WWS system among the 139 countries was already installed as of the end of 2015. The countries closest to 100% installation are Tajikistan (76.0%), Paraguay (58.9%), Norway (35.8%), Sweden (20.7%), Costa Rica (19.1%), Switzerland (19.0%), Georgia (18.7%), Montenegro (18.4%), and Iceland (17.3%). China (5.8%) ranks 39th and the United States (4.2%) ranks 52nd.

Footprint is the physical area on the top surface of soil or water needed for each energy device. It does not include areas of underground structures. Spacing is the area between some devices, such as wind, tidal, and wave turbines, needed to minimize interference of the wake of one turbine with others downwind. The total new land footprint required for the 139 countries is $0.22% of the 139-country land area (Table 2), mostly for utility PV.

This does not account for the decrease in footprint from eliminating the current energy infrastructure, which includes footprints for continuous mining, transporting, and refining fossil fuels and uranium and for growing, transporting, and refining biocrops. WWS has no footprint associated with mining fuels, but both WWS and BAU energy infrastructures require one-time mining for raw materials for new plus repaired equipment construction. The only spacing over land needed is between onshore wind turbines and requires $0.92%

| Energy Technology | Rated Power of One Plant or Device (MW) | Percent of 2050 All-Purpose Load Met by Plant/Device [a] | Nameplate Capacity, Existing plus New Plants or Devices (GW) | Percent Nameplate Capacity Already Installed 2015 | Number of New Plants or Devices Needed for 139 Countries | Percent of 139-Country Land or Roof Area for Footprint of New Plants or Devices[b] | Percent of 139-Country Area for Spacing of New Plants or Devices |
|---|---|---|---|---|---|---|---|
| Annual Average Power | | | | | | | |
| Onshore wind | 5 | 23.50 | 8,330 | 5.04 | 1,580,000 | 0.00002 | 0.9240 |
| Offshore wind | 5 | 13.60 | 4,690 | 0.26 | 935,000 | 0.00001 | 0.5460 |
| Wave device | 0.75 | 0.58 | 307 | 0.00 | 410,000 | 0.00018 | 0.0086 |
| Geothermal plant | 100 | 0.67 | 96 | 13.05 | 839 | 0.00023 | 0.0000 |
| Hydropower plant[c] | 1300 | 4.00 | 1,060 | 100.00 | 0 | 0.00000 | 0.0000 |
| Tidal turbine | 1 | 0.06 | 31 | 1.79 | 30,100 | 0.00001 | 0.00009 |
| Residential roof PV | 0.005 | 14.90 | 9,280 | 0.76 | 1,840,000,000 | 0.04030 | 0.0000 |
| Commercial/ goverment roof PV[d] | 0.1 | 11.60 | 7,590 | 1.16 | 75,000,000 | 0.03280 | 0.0000 |
| Solar PV plant[d] | 50 | 21.40 | 12,630 | 0.53 | 251,000 | 0.12800 | 0.0000 |
| Utility CSP plant[d] | 100 | 9.72 | 2,150 | 0.23 | 21,000 | 0.05270 | 0.0000 |
| Total for average power | | 100 | 46,200 | 3.76 | 1,919,518,000 | 0.255 | 1.480 |
| New land average power[e] | | | | | | 0.181 | 0.924 |
| For Peaking/Storage | | | | | | | |
| Additional CSP[f] | 100 | 5.83 | 1,290 | 0.00 | 12,900 | 0.032 | 0.000 |
| Solar thermal heat[f] | 50 | | 4,640 | 8.98 | 84,400 | 0.005 | 0.000 |
| Geothermal heat[f] | 50 | | 70 | 100.00 | 0 | 0.000 | 0.000 |
| Total peaking/ storage | | 5 | 6,000 | 8.11 | 97,300 | 0.037 | 0.000 |
| Total all | | | 52,200 | 4.26 | 1,919,616,000 | 0.291 | 1.480 |
| Total new land[e] | | | | | | 0.218 | 0.924 |

*Table 2. Number, Capacity, Footprint Area, and Spacing Area of WWS Power Plants or Devices Needed to Meet Total Annually Averaged End-Use All-Purpose Load, Summed Over 139 Countries*

All values are summed over 139 countries. Delucchi et al.26 provide values for individual countries. Annual average power is annual average energy divided by the number of hours per year.

a Total end-use load in 2050 with 100% WWS is from Table 1.

b Land area for each country is given in Delucchi et al.[26] 139-country land area is 119,651,632 km$^2$.

c The average capacity factors of hydropower plants are assumed to increase from their current world average values of $42% up to 50.0%.

d The solar PV panels used for this calculation are Sun Power E20 panels. For footprint calculations alone, the CSP mirror sizes are set to those at Ivanpah. CSP is assumed to have storage with a maximum charge to discharge rate (storage size to generator size ratio) of 2.62:1.

e The footprint area requiring new land equals the sum of footprints for new onshore wind, geothermal, hydropower, and utility solar PV. Offshore wind, wave, and tidal generators are in water, thus do not require new land. Similarly, rooftop solar PV does not use new land so has zero new land footprint. Only onshore wind requires new land for spacing area. Spacing area can be used for multiple purposes, such as open space, agriculture, grazing, etc.

f The installed capacities for peaking power/storage are estimated from Jacobson et al.[4] Additional CSP is CSP plus storage needed beyond that for annual average power generation to firm the grid across all countries. Additional solar thermal and geothermal heat are used for direct heat or heat storage in soil. Jacobson et al.[4] also use other types of storage.

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of the 139-country land area (Figure 1). The installed spacing area density of onshore and offshore wind turbines assumed here is less than indicated by data from dozens of wind farms worldwide, thus spacing requirements may be less than proposed here.

## ENERGY COSTS

In this section, current and future full social costs (including capital, land, operating, maintenance, storage, fuel, transmission, and externality costs) of WWS electric power generators versus non-WWS conventional fuel generators are estimated. These costs include the costs of CSP storage, solar collectors for underground heat storage in rocks and boilers, and all transmission/distribution costs, including additional short-distance A/C lines and long-distance high-voltage D/C lines.

We do not include here the cost of underground storage in rocks (apart from the cost of the solar collectors), the cost of pumped hydro storage, the cost of heat and cold storage in water and ice, or the cost of hydrogen fuel cells, but the section Matching Electric Power Supply with Demand provides a brief discussion that in- cludes these costs.

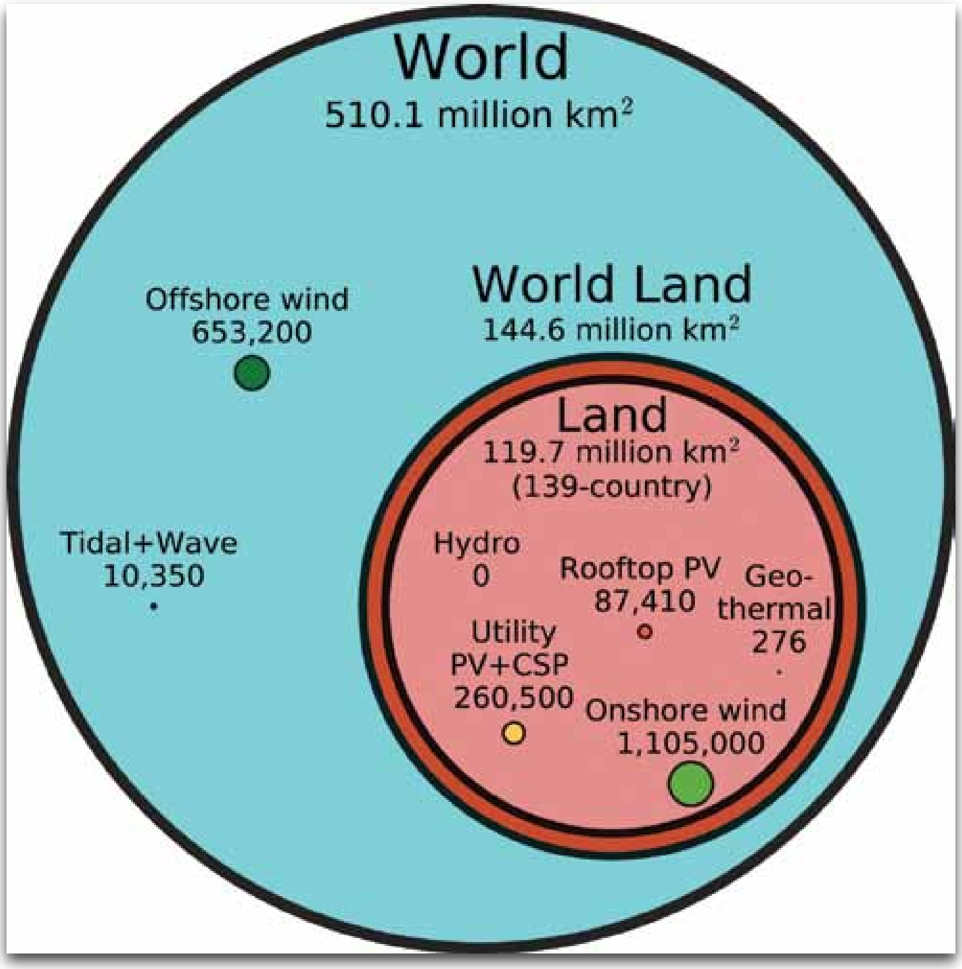


*Figure 1. Footprint Plus Spacing Areas (km2) Required Beyond Existing 2015 Installations, to Repower the 139 Countries Considered Here with WWS for All Purposes in 2050*

Table 2 gives the corresponding percentage of 139-country land area. For hydropower, the new footprint plus spacing area is zero since no new installations are proposed. For rooftop PV, the circle represents the additional area of 2050 rooftops that needs to be covered (thus does not represent new land).

The total up-front capital cost of the 2050 WWS system (for annual average power plus the peaking power and storage infrastructure listed in Table 2) for the 139 countries is ~$124.7 trillion for the 49.9 TW of new installed capacity needed (~$2.5 million/MW). This compares with ~$2.7 million/MW for the BAU case.

In addition, WWS has zero fuel costs, whereas BAU has non-zero fuel cost. To account for these factors plus operation/ maintenance, transmission/distribution, and storage costs, the Levelized Cost of Energy (LCOE) is needed.

The 2050 LCOEs, weighted among all electricity generators and countries in the BAU and WWS cases, are 9.78 ¢/kWh-BAU-electricity and 8.86 ¢/kWh-WWS-all- energy, respectively, excluding at this point any costs for peaking and storage. Taking the product of the first number and the kWh-BAU in the retail electricity sector, subtracting the product of the second number and the kWh-WWS-electricity replacing BAU retail electricity, and subtracting the amortized cost of energy-efficiency improvements beyond BAU improvements in the WWS case, gives a 2050 business cost saving due to switching from BAU to WWS electricity of ~$115/year per capita ($2013 USD).

Estimating an additional 0.8 ¢/kWh-WWS-electricity for peaking and storage in the BAU retail electricity sector from Jacobson et al.[4]

gives a WWS approximate business cost of $9.66 ¢/kWh-WWS-electricity, still providing ~$85/year per capita savings for WWS relative to just BAU's retail electricity sector.

## MATCHING ELECTRIC POWER SUPPLY WITH DEMAND

In the present study, we first calculate the baseline number of electric power gener- ators of each type needed to power each country based on the 2050 annually averaged WWS load in the country after all sectors have been electrified but before considering grid reliability and neglecting energy imports and exports.

We then use data from a 2015 grid-integration study for the US[4] to make a first-guess estimate of the additional electricity and heat generators needed in each country to ensure a reliable regional electric power grid (Table 2). Such estimates are then used as starting points in a separate, follow-up grid-integration study for 139 countries.

Although no information from the separate 139-country grid-integration study feeds back to the present study, results from that grid-integration study are briefly described here next to provide an idea of the 139-country average energy cost to keep the grid stable with 100% WWS.

In M.Z.J., M.A.D., M.A.C., and B.V. Mathiesen, unpublished data, each of the 139 countries is allocated to one of 20 world regions.

The numbers of wind and solar generators determined from the present study are input into the GATOR-GCMOM climate model[4] in each country. The model predicts the resulting wind (onshore, offshore) and solar (PV, CSP, thermal) resources worldwide every 30 s for 5 years, accounting for extreme weather events, competition among wind turbines for kinetic energy, and the feedback of extracted solar radiation to roof and surface temperatures.

The LOADMATCH grid-integration model[4] then combines the wind and solar resource time series with estimated time series for other WWS generators; hourly load data for each country; capacities for low-cost heat storage (in underground rocks and water), cold storage (in ice and water), electricity storage (in CSP with storage, pumped hydropower, batteries, and hydropower reservoirs), and hydrogen storage; and demand-response to obtain low-cost, zero-load loss grid solutions for each of the 20 grid regions.

In that study, it was found that matching large differences between high electrical demand and low renewable supply could be realized largely by using a combination of either (1) substantial CSP storage plus batteries with zero change in existing hydropower annual energy output or peak power discharge rate, (2) modest CSP storage with no batteries and zero change in the existing hydropower annual energy output but a substantial increase in hydropower's peak discharge rate, (3) increases in CSP-storage, batteries, and heat pumps, but no thermal energy storage and no increase in hydropower's peak discharge rate or annual energy output, or (4) a combination of (1), (2), and (3).

Thus, there were multiple solutions for matching peak demand with supply 100% of the time for 5 years without bioenergy, nuclear, power, fossil fuels with carbon capture, or natural gas.

In one set of simulations from M.Z.J., M.A.D., M.A.C., and B.V. Mathiesen, unpublished data, the resulting total costs of delivered 100% WWS energy, including generation, storage, short- and long-distance transmission, distribution, and maintenance, across all 139 countries in all 20 regions, was 10.6 (8.1–14) ¢/kWh-all-energy (USD, 2013) and 9.8 (7.9–12) ¢/kWh-WWS-electricity, the latter of which compares with the rough estimate of 9.7 ¢/kWh-WWS-electricity from the section Energy Costs here.

## AIR-POLLUTION COST REDUCTIONS DUE TO WWS

The costs avoided due to reducing air-pollution mortality in each country are quantified as follows. Global 3D modeled concentrations of $PM_{2.5}$ and $O_3$ in each of 139 countries are combined with the relative risk of mortality as a function of concentration and population in a health-effects equation.[27] Results are then projected to 2050 accounting for increasing population, increasing emission sources, and increasing emission controls.

Resulting contemporary worldwide outdoor plus indoor premature mortalities over the 139 countries are ~4.28 (1.2–7.6) million/year for $PM_{2.5}$, ~0.28 (0.14–0.42) million/year for $O_3$, and ~4.56 (1.33–7.98) million/year for both. Premature mortalities over the whole world are ~4.97 (1.45–8.65) million/year for both pollutants, which compares with 4–7 million/year (outdoor plus indoor) worldwide from other studies.[1,2,28-30] Premature mortalities derived for 2050 here are ~3.5 (0.84–7.4) million/year for the 139 countries.

The air-pollution damage cost due to fossil-fuel and biofuel combustion and

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evaporative emissions in a country is the sum of mortality, morbidity, and non-health costs such as lost visibility and agricultural output. Mortality cost equals mortalities multiplied by the value of statistical life. The resulting 139-country 2050 air-pollution cost due to 100% WWS is ~$23 ($4.1-$69) trillion/year, or ~12.7 (2.3–38) ¢/kWh-BAU- all-energy, which is ~7.6% (1.4%–23%) of the 2050 global annual GDP on a purchasing power parity basis and $2,600/year per person (in 2013 USD). Our air-pollution mean cost, which applies across all BAU sectors, is well within the 1.4–17 ¢/kWh-BAU-electricity range of another study for the retail electricity sector.[28]

## GLOBAL-WARMING DAMAGE COSTS ELIMINATED

Global-warming costs include costs due to coastal flooding and real-estate damage; agricultural loss; health problems due to enhanced heat stress and stroke, air pollution, influenza, malaria, and dengue fever; enhanced drought, wildfires, water shortages, famine, and flooding; ocean acidification; and increased severe weather.

In some regions, these costs are partly offset by fewer extreme cold events, associated reductions in illness and mortality, and gains in agriculture. Net costs due to global-warming-relevant emissions are embodied in the social cost of carbon dioxide, which is estimated for 2050 from recent studies as $500 ($282–1,063)/metric tonne-$CO_2$e in 2013 USD[7]. Applying this range to estimated 2050 $CO_2$e emissions suggests that 139-country emissions may cause $28.5 ($16.1–60.7) trillion/year in climate damage to the world by 2050, or 15.8 (8.9– 34) ¢/kWh-BAU-all-energy and ~$3,200/year per person (in 2013 USD).

## IMPACTS OF WWS ON JOBS AND EARNINGS IN THE POWER GENERATION SECTOR

Changes in job numbers and earnings resulting from building out 100% of the WWS electricity generation and transmission systems needed by 2050 are estimated with NREL's Jobs and Economic Development Impact (JEDI) models.[31] The models account for onsite "direct" jobs, local revenue and supply chain "indirect" jobs, and "induced" jobs from the spending and reinvestment of earnings from direct and indirect jobs.

The build-out of the WWS generation and transmission infrastructure produces jobs during construction and operation. All job numbers provided here are permanent, full-time (2,080 hr/year) jobs. Permanent direct, indirect, and induced construction jobs are calculated assuming that 1/L of total installed capacity is built or replaced every year, where L is the average facility life. Upon replacement of each facility, new construction jobs are needed. As such, construction jobs continue permanently. Job estimates do not include job changes in industries outside of electric power generation (e.g., the manufacture of electric vehicles, fuel cells, or electricity storage), as it is uncertain where those jobs will be located and the extent to which they will be offset by losses in BAU-equivalent industries.

Results indicate that 100% conversion to WWS across 139 countries can create $25.4 million new ongoing full-time construction-related jobs and $26.6 million new full-time, ongoing operation- and maintenance-related jobs, totaling 52.0 million new ongoing jobs for WWS generators and transmission.

Because WWS plants replace BAU fossil, nuclear, bioenergy, and BAU-WWS plants, jobs lost from not constructing BAU plants are also included. Jobs lost from the construction of petroleum refineries and oil and gas pipelines are also counted. Shifting to WWS is estimated to result in $27.7 million jobs lost in the current fossil-fuel, biofuel, and nuclear industries, rep- resenting $0.97% of the 2.86 billion 139-country workforce.

In summary, WWS may create a net of $24.3 million permanent, full-time jobs across the 139 countries. Whereas the number of operation jobs declines slightly, the number of permanent, continuous construction jobs far more than makes up for the loss. Individually, countries that currently extract significant fossil fuels (e.g., Algeria, Angola, Iraq, Kuwait, Libya, Nigeria, Qatar, and Saudi Arabia) may experience net job loss in the energy production sector. These losses can be offset by the manufacture, service, and export of technologies associated with WWS energy (e.g., liquid hydrogen production and storage, electric vehicles, electric heating and cooling, etc.). Those offsetting jobs are not included in the job numbers here. Collectively, the direct and indirect earnings from producing WWS electricity/trans-mission across 139 countries amount to:
~$1.86 trillion/year during construction and ~$2.06 trillion/year during operation. The annual fossil-fuel earnings loss is ~$2.06 trillion/year, yielding a net ~$1.86 trillion/year gain.

## TIMELINE

Figure 2 is a proposed WWS transformation timeline for the 139 countries. It assumes 80% conversion to WWS by 2030 and

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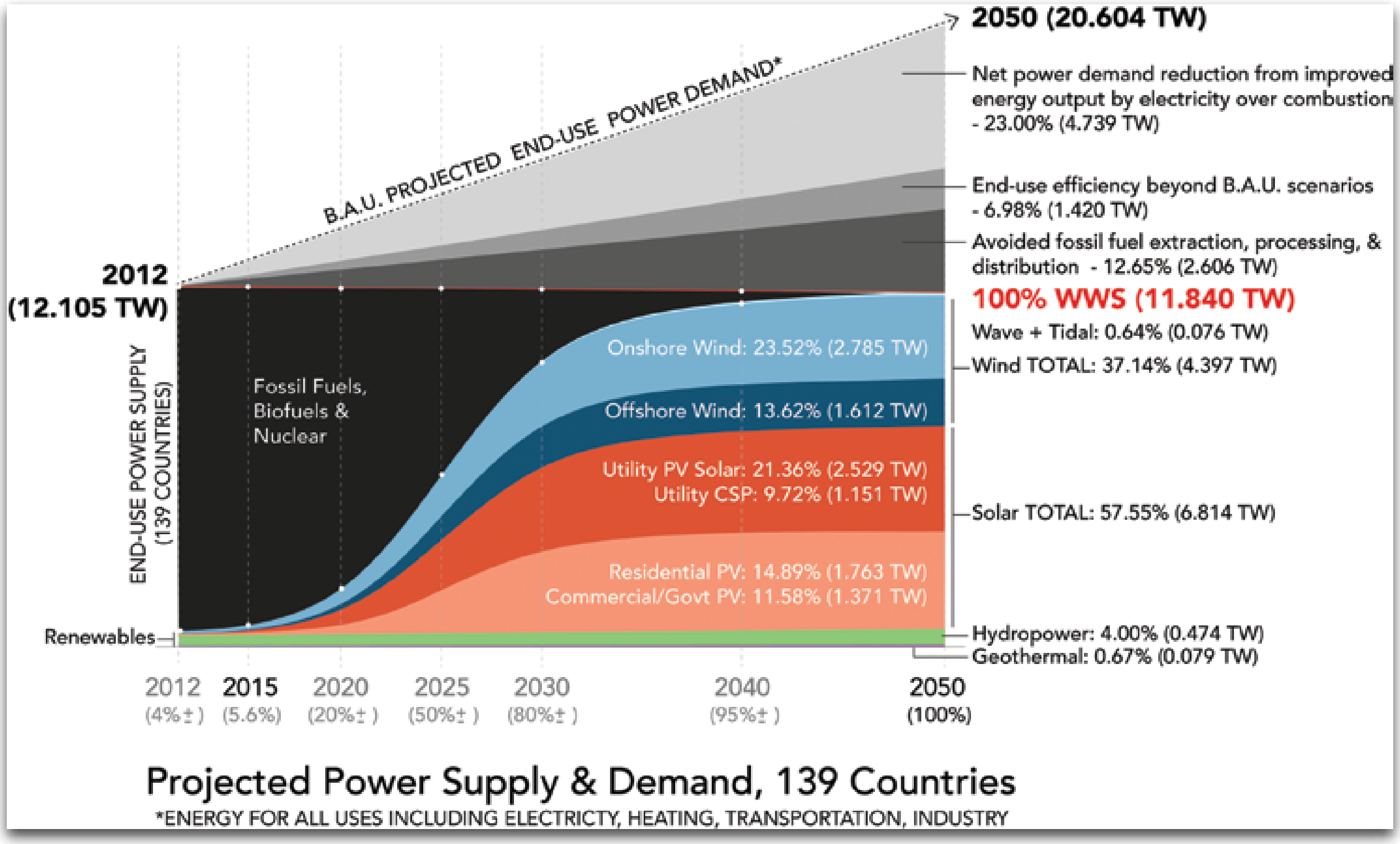


*Figure 2. Time-Dependent Changes in 139-Country-Summed, Annually Averaged End-Use Power Demand for All Purposes (Electricity, Transportation, Heating/Cooling, Industry, Agriculture/Fishing/Forestry, and Other) and Energy Supply in the BAU (Conventional Fuels) Case and as Proposed Here in the WWS Case*

100% by 2050. The rate of transformation is based on what is necessary to eliminate air-pollution mortality as soon as possible, what is needed to avoid 1.5˚C net global warming, and what we estimate is technically and economically feasible.

Friedlingstein et al.[32] estimate that, for the globally averaged temperature change since 1870 to increase by less than 2˚C with a 67% or 50% probability, cumulative $CO_2$ emissions since 1870 must stay below 3,200 (2,900–3,600) Gt-$CO_2$ or 3,500 (3,100–3,900) Gt-$CO_2$, respectively. This accounts for non-$CO_2$ forcing agents affecting the temperature response as well. Matthews[33] further estimates the emission limits needed to keep temperature increases under 1.5˚C with probabilities of 67% and 50% as 2,400 Gt-$CO_2$ and 2,625 Gt-$CO_2$, respectively. As of the end of 2015, $2,050 Gt-$CO_2$ from fossil-fuel combustion, cement manufacturing, and land use change had been emitted cumulatively since 1870,[33] suggesting no more than 350–575 Gt-$CO_2$ can be emitted for a 67%–50% probability of keeping post-1870 warming under 1.5 C. Given the current and projected global emission rate of $CO_2$, it is necessary to cut energy and land use change emissions yearly until emission cuts reach 80% by 2030 and 100% by 2050 to limit warming to 1.5 C with a probability of between 50% and 67%.

Whereas much new WWS infrastructure can be installed upon natural retirement of BAU infrastructure, new policies are needed to force remaining existing infrastructure to be retired early to allow the complete conversion to WWS. Because the fuel, operating, and external costs of continuing to use existing BAU fossil-fuel capacity are, in total, much greater than the full annualized capital-plus-operating

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costs of building new WWS plants (indeed, the climate and air-pollution costs alone of BAU infrastructure, 28.5 [11.2–72] ¢/kWh-BAU-all-energy, exceed the full cost of new WWS infrastructure), and because substitution of WWS for BAU energy systems increase total jobs, it is beneficial to society to immediately stop operating existing BAU fossil- fuel plants and replace them with new WWS plants.

## CONCLUSIONS

Transitioning 139 countries to 100% WWS has the potential to:
(1) avoid ~4.6 (1.3–8.0) million premature air-pollution mortalities/year today and 3.5 (0.84–7.4) million/year in 2050, which along with non-mortality impacts, avoids ~$23 ($4.1–69) trillion/year in 2050 air-pollution damage costs (2013 USD);
(2) avoid ~$28.5 ($16.1–60.7) trillion/year in 2050 global-warming costs (2013 USD);
(3) avoid a total health plus climate cost of ~28.5 (11.2–72) ¢/kWh-BAU-all-energy, or $5,800/year per person, over 139 countries;
(4) save ~$85/person/year in BAU-electricity-sector fuel costs;
(5) create ~24.3 million net new permanent, full-time jobs;
(6) stabilize energy prices;
(7) use minimal new land (0.22% of 139-country land for new footprint and 0.92% for new spacing);
(8) enable countries to produce as much energy as they consume in the annual average;
(9) increase access to distributed energy by up to 4 billion people worldwide currently in energy poverty; and
(10) decentralize much of the world power supply, thereby reducing the risk of large-scale system disruptions due to machinery breakdown or physical terrorism (but not necessarily due to cyber attack).

Finally, the aggressive worldwide conversion to WWS proposed here may help avoid global temperature rising more than 1.5°C since 1870. While social and political barriers exist, converting to 100% WWS using existing technologies is technically and economically feasible.

Reducing the barriers requires disseminating information to make people aware about what is possible, effective policies, and individuals taking actions to transition their own homes and lives.

## EXPERIMENTAL PROCEDURES

Quantifying the numbers of WWS generators in each country begins with 2012 energy-use data[3] in each energy sector of 139 countries for which data are available. Energy use in each sector of each country is projected to 2050 from the 2012 data in a BAU scenario. The projections account for increasing demand; modest shifts from coal to natural gas, biofuels, bioenergy, and some WWS; and some end-use energy-efficiency improvements.

All energy-consuming processes in each sector are then electrified, and the resulting end-use energy required for a fully electrified all-purpose energy infrastructure is estimated. Some end-use electricity is used to produce hydrogen for long-distance ground, ship, and air transportation. Modest assumed additional end-use energy-efficiency improvements are then applied. The remaining power demand is supplied with a combination of different WWS technologies determined by available natural resources and the rooftop, land, and water areas in that country.
The WWS electricity generation technologies assumed include onshore and offshore wind turbines, CSP, geothermal heat and electricity, rooftop and utility-scale solar PVs, tidal and wave power, and hydropower. These are existing technologies found to minimize health and climate impacts compared with other technologies, while also minimizing land and water use.[22]

Technologies for ground transportation include battery electric vehicles (BEVs) and BEV-hydrogen fuel cell (HFC) hybrids, where the hydrogen is electrolytic (produced by electrolysis or passing electricity through water).

BEVs with fast charging (an existing commercial technology) dominate short- and long-distance, light-duty ground transportation, construction machines, agricultural equipment, short- and moderate-distance trains, short-distance boats and ships (e.g., ferries, speedboats), and aircraft traveling less than 1,500 km.

BEV-HFCV hybrids dominate medium- and heavy-duty trucks and long-distance trains, ships, and aircraft. HFCs are not used to generate electricity due to the relative inefficiency and associated costs of this application. In this study, ~7.0% of all 2050 WWS electricity (43.6% of the transportation load) is for producing, storing, and using hydrogen.

Currently, several companies are developing electric commercial aircraft for travel up to 1,500 km, and a four-seat HFC aircraft with a range of 1,500 km has been developed. We believe such technology can become mature by 2035 and 2040, respectively, by the time we propose that they comprise all new aircraft.

Air heating and cooling are powered by ground-, air-, or water-source electric heat pumps. Water heat is generated by heat pumps with an electric resistance element for low temperatures and/or solar hot water preheating. Cooking stoves are electric induction.

Electric arc furnaces, induction furnaces, and dielectric heaters are used to power high-temperature industrial processes directly.

The roadmaps assume the adoption of new energy-efficiency measures but exclude the use of nuclear power, carbon capture, liquid and solid biofuels, and natural gas primarily because the latter sources all increase air pollution and climate-warming emissions more than do WWS technologies and because the use of nuclear power entails serious risks that WWS systems do not have.[22]

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# Independent Power Producers

There has been a high demand for independent power producers in South Africa, and speculation surrounding the introduction of nett-metering by Eskom to support the industry is imminent.

**BY |** KEVIN BRUCE JACOBS

The purchase agreements and payback periods for investment are still open for discussion as the power utility needs to support the growing grid demands as well as purchasing the energy at prices the consumers can afford, considering the current market conditions.

The delay by Eskom to approve the IPP (Independent Power Producers) and PPAs (Purchase Price Agreement) has not been to the detriment of the consumer. The financial cash flow constraints facing Eskom, is due to consumers (public and private sectors) not paying their utility bills.

Had the IPP and PPAs been rolled out with the current industrial and commercial trends, Eskom would not have been able to pay the IPP's, which would have resulted in large scale project failures.

The companies which have invested a large amount of capital without the need to payback large loans are sitting in better positions. As soon as the PPA agreements are finalized, the consumers will understand the financial impact of the decision.

The approval of IPPs bodes well for the environment which welcomes the introduction of green energy. Currently, most consumers are looking to install their own solar energy to supplement their current power utility feed and the surplus energy can be fed back into the grid, to be purchased by the energy utility at a predetermined rate. Investors can now also build independent power utilities consisting of solar, hydro, biomass, wind or gas to aid Eskom in providing additional power to the grid. This removes a large financial burden off the power utility who can focus on upgrading and maintaining its current infrastructure to facilitate the introduction of new energy sources.

Technically, the introduction of energy sources produces a different risk onto the network, which was designed and installed for a specific consumer demand at a specified fault level. The introduction of new energy sources onto the grid influences the fault level on the existing infrastructure, leading to required upgrades to support the new energy sources. There are a multitude of factors including trip settings and isolation procedures which need to be reviewed to ensure that there is no back feed onto an isolated circuit for electrical workers performing maintenance on the grid. The safety of personnel is of utmost importance when dealing with multiple sources feeding onto a single bus. The way in which the supply is synchronized with the main supply is also of importance. Each independent supply needs to be synchronized with a synchronizing pulse to ensure that the grid maintains its supply integrity, to deliver the power at the specified quality provided by the power authority. The independent power producers should have the capability to isolate the supply circuit automatically, should the main supply fail and/or the synchronizing signal fails or if the supply becomes asynchronous due to any internal faults and/or failures.

There is no downside to the approval of IPP, providing the PPAs are reasonable to the consumer and it does not result in an overall increase in the consumer supply charges for energy to supplement the grid upgrade, maintenance and sustain ability.

This will only have a negative effect on industry as well as residential consumers whom are currently struggling to pay their bills in the ailing economy. wn

# We are having the Wrong Conversations!

Because of the ongoing discussions around our electricity utility, load shedding in the recent past and requests for exorbitant tariff increases for electricity, electrical energy has remained top-most in peoples' minds.

**BY** I VIV CRONE I PR ENG, FSAIEE

It is clear that although we have enough generating capacity currently, any developing country will require more and more energy as their economies grow and living standards improve. It is clear therefore that more generation capacity will have to be provided into the future. Normally this will require the building of large power stations fuelled by coal, uranium, oil or natural gas. Current discussions, debates and conversations rage around which technology, which fuel, which location for these power stations have to be implemented. Society is spending an inordinate amount of time on these discussions with special interest groups stating cases for and against the various options.

I think we are having the wrong conversation!

The decision to build a new power station is a decision that will determine a very costly course for the next 60 to 70 years. After the basic decision has been made and assuming that the project is urgently implemented, a power station will take between 10 and 15 years to complete. After commissioning, a working life of 40 to 50 years is expected and may be further extended with life extension programs.

I suggest that these current discussions and decisions do not adequately take the accelerating progress of technology into account!

Let's step back for a moment. Sixty years back.

It is the late 1950s, Volare was the number 1 hit song; Sputnik 1, launched the previous year fell back to earth; the first American satellite was launched; the Lego brick was patented; the hula hoop became a national craze; the world's population was 2.9 billion; the first integrated circuit was developed; the first transatlantic commercial airline service (BOAC using Comet aircraft) was started.

There was no colour TV in Europe, no mobile phones, no internet, no personal computers, cordless tools were limited by the use of NiCad batteries and space exploration was in its infancy.

Fast forward to today; ubiquitous, low-cost computing resources, universal connectivity, internet, low cost world-wide communications. New innovations include the internet of things, cost effective renewable energy, hybrid and electric vehicles, robots, blockchain.

But now let's move forward and ask what will the next 60 years bring?

It is important to note that historically, society has been very poor at predicting how technology will progress! For example, IBM noted in 1943 that, *"I think there is a world market for maybe five computers."* (Thomas Watson, President of IBM)
*"There is no reason anyone would want a computer in their home."* (Ken Olsen, founder of Digital Equipment Corporation, 1977)

# Wrong Conversations

*continues from page 53*

*"Remote shopping, while entirely feasible, will flop."* (Time Magazine 1966)
*"The subscription model of buying music is bankrupt."* (Steve Jobs 2003)
*"I predict the Internet in 1996 [will] catastrophically collapse."* (Robert Metcalfe. Co-inventor of Ethernet 1995)
*"Cellular phones will absolutely not replace local wire systems."* (Marty Cooper, inventor of the mobile phone 1981)
*"640k ought to be enough [memory] for anybody."* (Bill Gates, Microsoft founder, 1981)

While some of the above predictions were made more than 60 years ago, many were made more recently and all have turned out to be simply wrong!

I don't believe that the future predictions will necessarily be better but I am a great believer in what I call 'Flare' technologies. The term comes from the imagining that one stands on a high point on a moonless dark night and suddenly a flare is deployed lighting up the surrounding area. In the same way there are technologies that may still be in their infancy that will 'light up' their surroundings, having a very significant influence on our future? An example of one such technology is 3D printing that leads to additive manufacturing. This will change all of our lives in fundamental ways!

So which technologies are 'on deck' that could be regarded as flare technologies that will affect the energy industry?

Perhaps large energy storage technologies e.g. batteries, electric vehicles, solar cell efficiency improvements, SMRs (Small Modular [nuclear fission] Reactors), 'Smart' Grids, blockchain are a few? These and others will change the very nature of how electrical energy is generated, distributed and used in future years.

Let's look at these one at a time:

## SOLAR CELL EFFICIENCY IMPROVEMENTS

Currently industry standard solar cell efficiency lies between 10% and 20%. This means that a typical household of 200 $m^2$ would require somewhere around 32 $m^2$ (8 m by 4 m) of well positioned roof area covered with a solar panel array, that would supply 5kW peak power and around 25 kWh of energy per sunny day.

A home with different energy sources for heating and cooking can get by on a 3 kW peak array taking up around 20 $m^2$ of roof and supplying 15 kWh per sunny day. Use of efficient lighting, better building design to reduce the heating and cooling requirements, scheduling high power appliances already make this a viable solution.

However, since 2017 mass-produced solar cells with an efficiency of over 26% are now available. Research lab results have exceeded an efficiency of 50% with a theoretical efficiency limit of 63%. This would mean an increase of between 3 and 4 times the daily energy supply of today!

Of course a major disadvantage of a solar system is that it only supplies energy during the daylight hours. Many households use most of their electric energy after the sun has set!

Going back to our above example, now the energy available on a daily basis could be up to 100 kWh per day! It is obvious that if the above 'excess' energy could be stored then the major disadvantage of the intermittency of renewable energy would be overcome and excess energy could be sold or used for other purposes.

## ELECTRICAL ENERGY STORAGE

Several different energy storage technologies are mooted. These include gas-turbine battery hybrid systems, compressed air systems, and batteries, to mention a few. I will focus on battery technology here.

We are all familiar with the lead acid battery that forms the storage element in many of today's solar systems. If used, current battery storage technology accounts for approximately 50% of the cost of a home solar system. In addition, the batteries have a limited lifetime and have to be regularly replaced.

However a tremendous amount of time and money is being spent on developing new and improving existing battery technologies.

During December 2017 a 100 MW, 129 MWh capacity 'battery' was commissioned in Southern Australia alongside an existing wind power energy facility. The intention of this is to 'fill-in' the gaps in the daily wind energy profile. The battery is capable of providing around 30 MW within 4 seconds and can supply this power level for 3 to 4 hours per day.

An impressive side-story is that this project was supplied and commissioned in less than 100 days (as a bet by Elon Musk - if the deadline was not met, the battery would be supplied free!)

Current battery technology is expensive. However battery costs have decreased by

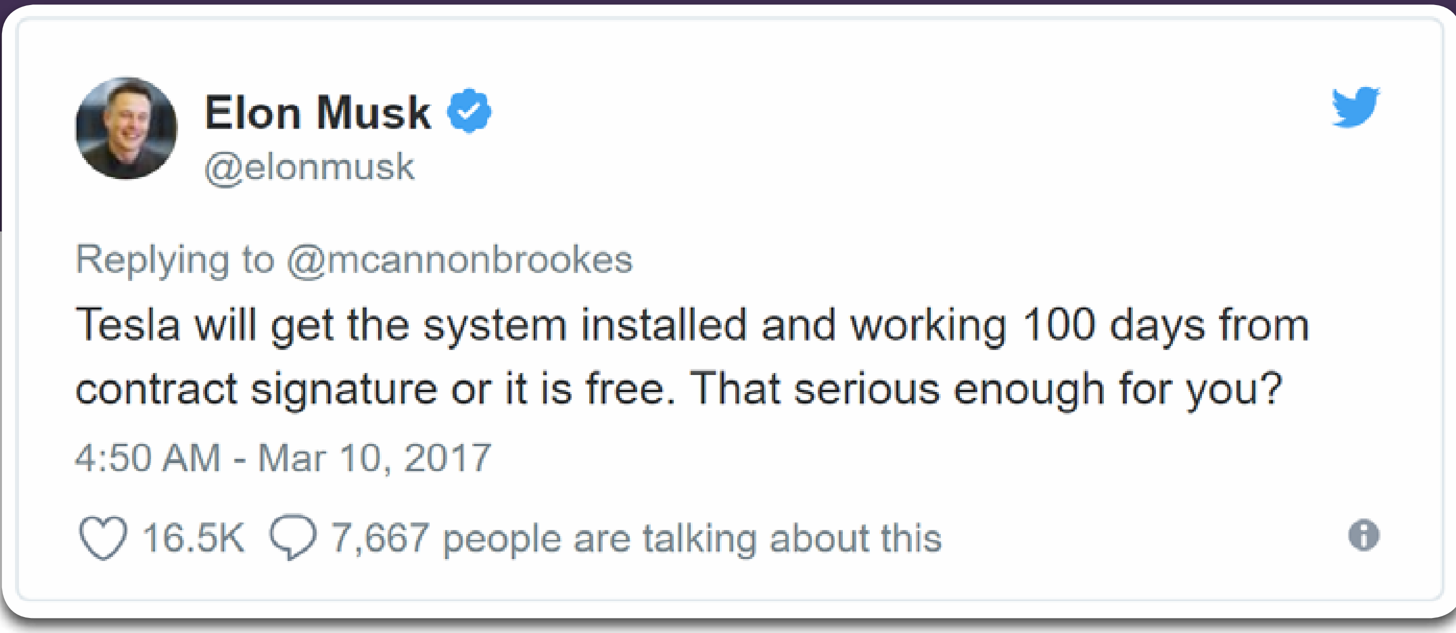



*Figure 1: Elon Musk's tweet*

73% since 2010 and further significant decreases are predicted.

There are many different battery technologies currently being developed and tested but it is predicted that the cost of vehicle batteries will reduce from the current cost of around $150/kWh to $50 /kWh by 2030. This will have a dramatic positive effect on the viability of home and other solar electricity projects as well as transport! Which brings us to the next rapidly emerging technology – electric motor vehicles.

## ELECTRIC CARS

Volvo has stated that its cars from 2019 onwards will be either completely or partially battery powered! Between 2019 and 2021 five all-electric models will be introduced.

Other car manufacturers such as Renault, BMW and VW have all made public their plans for electric cars. A recent newspaper article states that India will push for all new cars to be electric by 2030. Current electric cars have a battery capacity of around 30 kWh equal to about 1.5 times the consumption of a sensible household.

(However the Tesla Model S has a battery capacity of 85 kWh!)

With more efficient solar panels, the solar powered household of the future will have more than enough electric energy to recharge 1 or 2 electric cars overnight! The vehicle batteries could also be used to store some of the excess generated energy and provide it when needed. For example the peak household energy in the early evening could be provided by the vehicle battery, without seriously depleting its charge for the next day.

## SMALL MODULAR [NUCLEAR FISSION] REACTORS (SMR)

Many of us will remember the PBMR (Pebble Bed Modular Reactor) Project that was 'canned' by the SA Government in 2010 after significant development expenditure. It may therefore come as a surprise that there are several ongoing projects around the world to develop a Small Modular Reactor with a target of 2024 for the first deployment.

Ranging in capacity up to 300 MWe (Megawatts Electrical), these pre-manufactured plants are intended not only for power generation but also to power desalination facilities and as carbon-free 'drop-in' replacements for existing fossil fueled plants. If additional energy is required at a site, additional SMRs could be added or 'stacked'.

Currently the nuclear industry is in crisis as the current large projects are mostly bespoke designed, essentially being one-offs. They end up being very costly to start and generally overrun in both costs and time before eventual commissioning. SMRs, on the other hand, will have reduced capital investment, can be deployed in areas that could not accommodate larger plants with up-to-date improvements for better security and safety. Further, they can be standardized, manufactured in quantity and shipped to site for final assembly. This would substantially reduce the costs of nuclear energy with some projections showing that they will match the costs of gas powered plants by 2030.

## SMART GRIDS

A Smart Grid is a modernized electricity grid that takes advantage of ubiquitous computing power and two-way data communication to more efficiently manage and control the measurement, monitoring, consumption, generation and maintenance of the electricity supply.

The previously discussed technologies will be 'embedded' into the existing overall electricity system and as such will make up a number of interacting sub-grids with energy sources and sinks.

# Wrong Conversations

*continues from page 55*

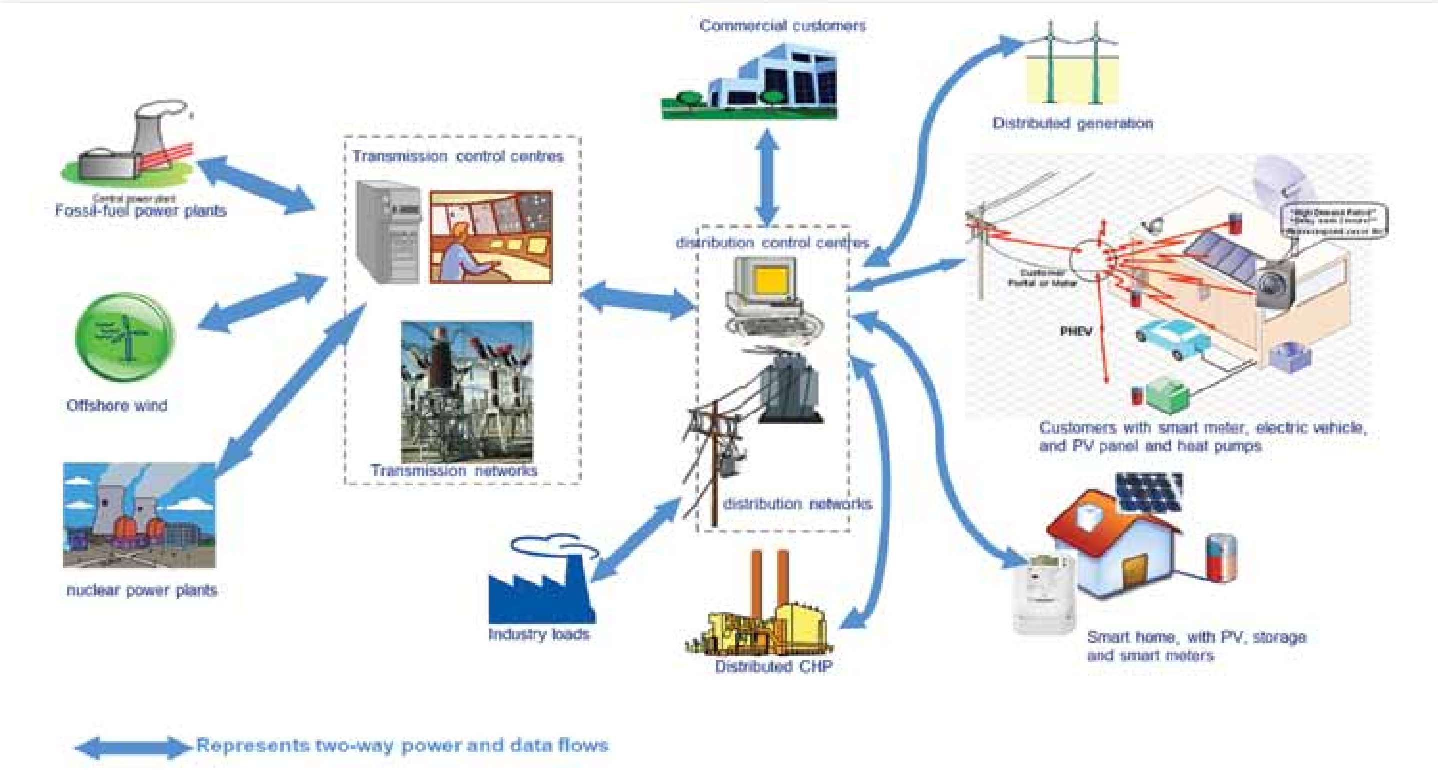



*Figure 2: Smart Grid Example (Merz and McLellan)*

These will require significant management to ensure the control of voltage and frequency and measurement of the electricity flows into and out of various nodes and not least of all, the sale and billing of the energy.

Ultimately the 'grid' will consist of a large number of interacting sub-grids that will have to be controlled and managed as parts of the overall electricity system. Up to now, this has not been possible while ensuring the stability of the grid to avoid blackouts such as those that occurred in the northeastern US in November 1965 and on August 2003. However with the availability of ever-increasing low-cost computer power and the advent of the Internet of Things, tight control and management of multiple interacting sub-grids will be possible.

## BLOCKCHAIN

Tying all of the above together will be the ability of anyone that is connected, to buy and sell energy as his/her supply and demand ebbs and flows.

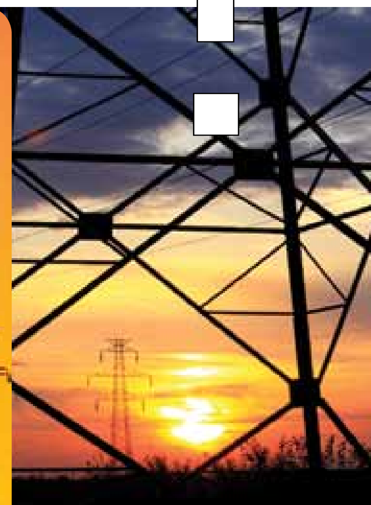
For example, should a household have excess energy, this could be sold into the electricity system for tokens that can be spent at another time to buy energy back when necessary.

Blockchain technology promises to provide a secure, disintermediated, low transaction cost environment that will enable high volumes of transactions between the end-users of electricity. I have tried to present a picture using the above either available or short horizon technologies that essentially shows that large centralized power stations will rapidly become obsolete. Building more new large power stations will only add to this obsolescence! The above scenarios are constructed using readily available current data. How does one know what innovations lie around the corner that will further significantly change everything?

I firmly believe that the trend towards embedded energy systems making use of the technologies above and others still to come will eliminate the requirement for large centralized power stations in the near future.

So residents of Thyspunt and Duynefontein; Relax! Conversations as to where to situate the next soon to be obsolete large nuclear or coal-fired mega power stations are a waste of 'energy'!

It is the wrong conversation! wn



IN MY OPINION - BUBELE NYIBA

OPINION

# Industry Waste Management Plans

In December 2017, the government issued a gazette requiring the paper and packaging, electric and electronic, and lighting industries to prepare and submit Industry Waste Management Plans within nine months of the publication of the gazette. The three industries must submit Industry Waste Management plans by 6 September 2018. In addition, all producers in these industries must register with the department of energy within two months of the publication of the gazette.

**BY** | BUBELE NYIBA | CEO OF THE ROSE FOUNDATION

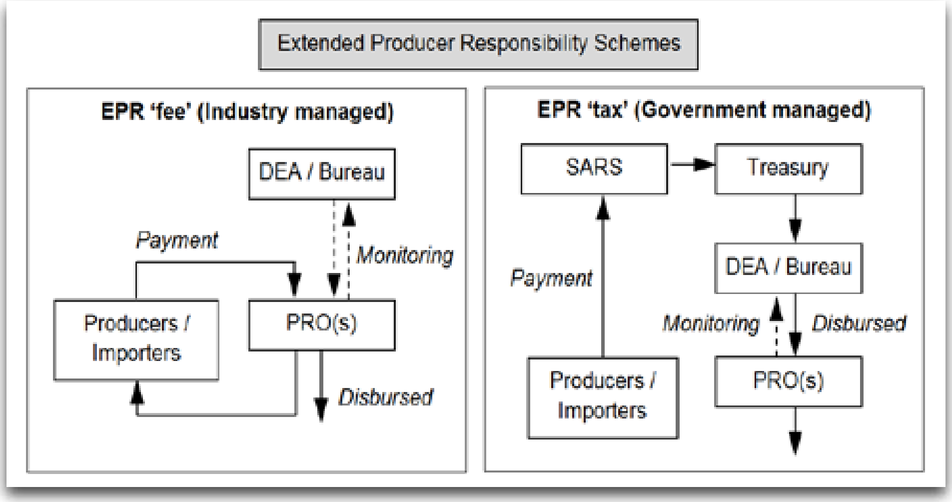
All this is happening against a backdrop of the dismal history of failures in the plastic bag and tyre waste sector systems. The plastic bag initiative was government driven, while the tyre initiative was industry-driven. One hopes that lessons have been learnt and future plans will mitigate against another unsuccessful implementation of a sector plan.

## LEVIES AND JOB CREATION

The latest call for industry waste management plans is a step in the right direction to achieve government's goal of zero waste to landfill. The government must be lauded for enforcing responsibility for the full product lifecycle with manufactures and importers. This is a worldwide practice, and South Africa should be no exception. It a huge opportunity to create job opportunities in the collection, transportation, storage and processing of waste.

Industry waste management plans reduce the opportunity for fence-sitting. They eliminate free riders and convoluted conspiracy theories, which are the Achilles heel of voluntary schemes. Hopefully, they will also kill off the unfortunate notion that industry should pay to have waste collected in voluntary schemes. Both public and private sectors role-players regrettably subscribe to this view that that is not supported by evidence, but continues to influence behaviour and practice.

On the other hand, the call for industry waste management plans could have a negative impact to those who will ultimately bear the brunt of regulated levies for waste collection and disposal. The negative comes only if it is not foreseen that the cost of recycling will be borne by the ultimate consumers of the products. Whenever the government or industry imposes a levy on a product, the producers merely add the levy to




*Pricing strategy models for Extended producer Responsibility schemes*

the cost of production. To illustrate this point, consider the price of a litre of petrol. All the levies are tabulated separately and form part of the cost structure for the litre the consumer buys at a service station. The more the levies increase, the more expensive fuel becomes. Customers have to pay for whatever levy is agreed upon and implemented.

## WASTE COLLECTION EPR MODELS

The government envisages two models or schemes for the management of producer responsibility organizations and the related collection of levies, namely, government versus industry managed schemes. In the industry managed scheme, an industry association effectively coordinates and facilitates all the recycling activities of that industry's waste stream, and also collects their own levies directly from producers (indirectly from consumers). Naturally, but not always obviously, the customer is still the ultimate the payer of the levy.

Alternatively, there would be a government managed scheme run directly by government or more likely by an organization directly under government supervision. Under the government managed scheme, the government collects the levies, via Treasury. There are three very significant downsides to a levy collected via central government. The first is that the government will impose an administrative fee of up to a quarter of the collected levies. So from the get go, the recycling kitty reduces by 25% as a function of who collects the funds. Second, and most worrisome, there is no guarantee that the funds for recycling will be ringfenced towards the purpose for which they were collected. Lastly, the consumer will ultimately pay more per kilogram for the recycling of waste. To achieve the same goals as the industry managed schemes, the customer must have the burden of an administered price from which there is no escape. No matter how much we could try, incorrect strategies implemented correctly could never achieve the best results.

If it is true that all solutions somehow have winners and losers, then it is fair to say that in the government managed scheme, the customer is the loser and the national fiscus is the winner. In the industry managed scheme, the opposite is true, if the scheme is efficiently managed. It is not difficult to understand why industry managed or government managed schemes should work in collaboration with the Waste Bureau from the Department of Environmental Affairs. The government needs to have sight of what is happening within each waste stream, and that could be easily and without much fanfare.

## PRODUCER RESPONSIBILITY AND PLANNING

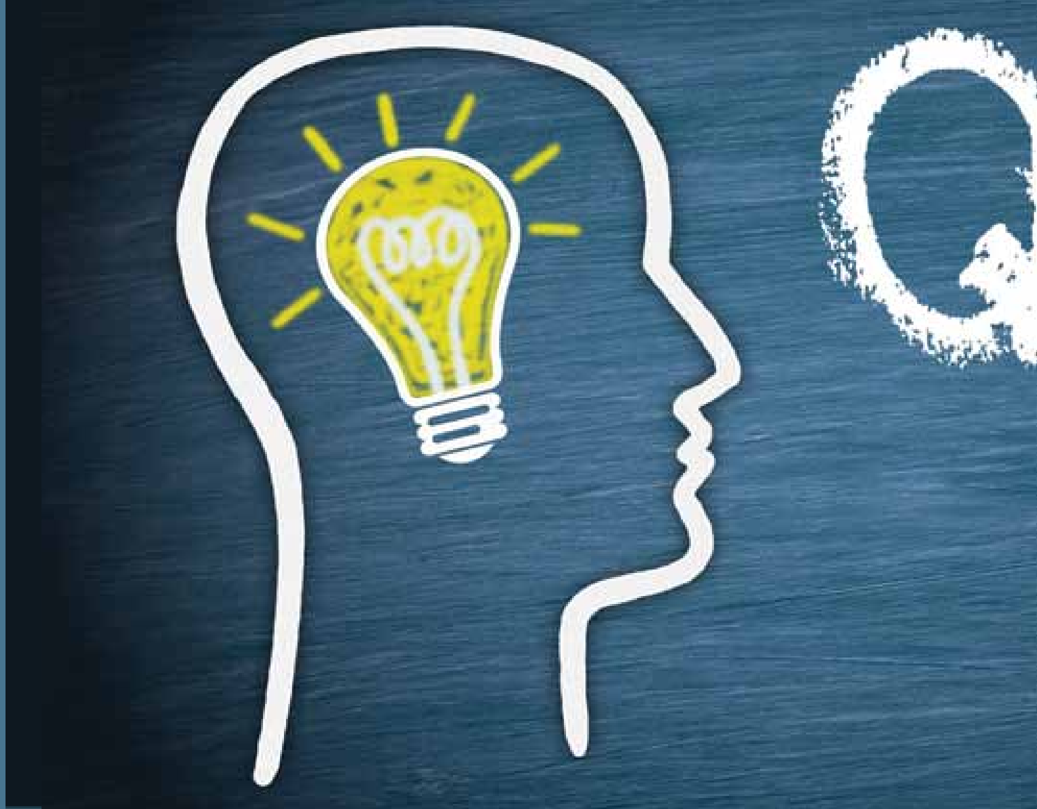
The development and implementation of industry waste management plans have to be the responsibility of producer industry associations. Industry has to be responsible for the collection and disbursement of levies under tight governance controls. Generally, industry associations have a long history of robust corporate government without any one player allowed to exercise dominance.

The place for creativity, craftsmanship, and business skills should be exercised somewhere else down the value chain. The collection, transportation, storage, and processing of waste is a large enough space to allow for entrepreneurs to apply their skills and experience to earn a living and to create employment. The anomaly in the tyre industry should be considered a misstep that should not be repeated. Placing producer responsibility organizations in self-interested companies or private hands, however disguised, is a recipe for disaster.

Similarly, independent non-profit organizations that are removed from the producers is an opportunity to manufacture malfeasance and news grabbing practices that are not related to reducing waste to the landfills and protecting the environment. The interface with the Waste Bureau is a good step so that the government is always in the loop regarding the activities of each waste stream. Otherwise the government will have a complete outsider view of what is happening and base its decisions on assumptions rather than what is the real situation.

We have to view these latest developments as an opportunity to create the right systems and architecture for the waste industry. We have an opportunity to do it right and minimize any unintended consequences of our actions. We have the hindsight of having implemented two incorrect approaches incorrectly, and not surprisingly, both haven't been a resounding success.

Now is a perfect opportunity to implement the correct processes correctly. We owe it to the future of our environment and future generations. wn



**WATT?** is a forum related specifically to the industrial and commercial electrical sector.

Do you have any burning questions, topical issues or points of interest about the electrical industry, from the perspective of a contractor, supplier or professional service provider? Submit your comments, thoughts, ideas, suggestions or questions for the attention of our industry experts, and these will be addressed in a future issue of the magazine. This is your forum, and we would like to hear from you!

WATT? is an opportunity for people on the ground to engage with each other and related professionals in an informative and friendly manner. This is a platform for you to discuss anything related to your particular sector, to highlight anything new, or to ask a specific question related to a technical topic or to engage in general industry issues. . Please note that we will not be considering anything related to the domestic sector, such as residential wiring.

We hope that this section of the magazine not only becomes a regular feature, but that it is widely read and distributed among your peers. Remember, it can only become a success with the full participation of our readers! Send your burning questions to minx@saiee.org.za - subject 'WATT?'.

We look forward to hearing from you.

*- Ed*

NRS 048 Part 2 is a specification dealing with electricity quality of supply. As such, it is sometimes used to specify performance criteria for certain equipment. The following questions explore some facets of this

## QUESTION ONE

Can NRS048 be applied in order to ride through dips and thereby prevent a trip on an essential item of equipment such as a vent fan or boiler feeder?

## ANSWER ONE

Sometimes an end user experiences problems resulting from poor Quality of Supply (QOS). Simply put, there are voltage dips on the user's supply and some of these dips are severe enough to result in essential items of equipment tripping. NRS048 is a user specification issued by Eskom which specifies QOS parameters as well as probability and compatibility levels. The working group considered the relevant international standards, the actual occurrence of voltage dips in South Africa and then specified compatibility levels such that the compatibility covers 95% of the probability. The dip levels, duration and frequency were statistically calculated and can therefore not be guaranteed. However, having said that, the working group had many people with significant experience and knowledge. It can therefore, be accepted that the values provided are good enough with which to work. Where a specific situation exists that falls outside of the norms, specific measurements will have to be taken and mitigating steps implemented.

Most electrical equipment used in South Africa should comply with long established European standards. These standards cover the equipment performance criteria, build quality etc. These equipment standards would not generally include NRS048 compliance. Therefore, compliance with NRS048 requires some insight into the equipment technology as well as the end user application. For example, almost all Variable Speed Drives (VSDs) can ride through a voltage dip Y and X1 as defined by NRS048. However, if we consider two different examples we can see different practical results in the applications.

E.g. The user specifies that NRS048 voltage dip ride through compatibility with NRS048 4.2.9 Table 7, type X1 and Y is required.

| | |
|---|---|
| X1 = | 15 to 20% dip for 20 to 150 mSec. |
| Y = | 20 to 30% dip for 20 to 150 mSec |
| | 15 to 20% dip for 20 to 600 mSec |
| | 10 to 15% dip for 20 to 3000 mSec |


The VSD vendor may correctly reply that his equipment complies.

Application A:
A ventilation fan, Pabs = 65kW, 1450RPM, 110kW 4 pole motor installed
Application B:
Uphill conveyor, Pabs = 100kW, 800RPM, 110kW 4 pole motor installed

At the same customer, and using the same make and model of VSD that is fully compliant with all the relevant standards, two very different ride through results will be achieved.

Application A will ride through all dips, shown green below.

X1 = 15 to 20% dip for 20 to 150 mSec.
Y = 20 to 30% dip for 20 to 150 mSec
15 to 20% dip for 20 to 600 mSec
10 to 15% dip for 20 to 3000 mSec

Application B will ride through some dips, shown green below and trip during others, shown red below.

X1 = 15 to 20% dip for 20 to 150 mSec.
Y = 20 to 30% dip for 20 to 150 mSec
15 to 20% dip for 20 to 600 mSec
10 to 15% dip for 20 to 3000 mSec

This shows that it is not simply a matter of equipment specification but also of engineering application. Often end users do not want to go to the additional effort of understanding the various loads in their plant and then simply specify that dip ride through must be according to NRS048 4.2.9 Table 7, type X1 and Y regardless of load characteristic. This may result in VSD units being oversized (overpriced) or customised at great cost when it is not necessary. Additionally the non-standard units will probably become a maintenance problem in the years to come.

The answer to the question then is: Yes, NRS048 can be applied but in conjunction with sound engineering.

## QUESTION TWO

Can NRS048 be used to prevent excessive voltage distortion due to VSD generated harmonics?

## ANSWER TWO

Yes, the individual and maximum distortion guidelines in NRS 4.2.5 Table 6 may be used. Once again, however, the specification cannot be applied to individual items of equipment and viewed in isolation from the rest of the plant as a whole.

For example NRS048 requires that Voltage Total Harmonic Distortion (Vthd) does not exceed 8%. In general, a VSD supplier can comply with this very easily. However, though each individual VSD unit may comply, the sum total of all installed VSDs may not comply.

Additionally it may be that the customer already has, for example, 6% Vthd. The addition of even a relatively small VSD load may result in the Vthd being above 8%. This would not necessarily be due to substandard VSD design but due to the pre-existing harmonic distortion.

Clearly it is not a simple matter of specifying a certain standard for the equipment. The user should know what the pre-existing Vthd levels are and also what the total VSD load will be.

Based on this it can be determined whether NRS048 specification will be met. wn

*Information provided by Zest WEG Group*

# February

Movers, shakers and history makers

**COMPILED BY** | JANE BUISSON-STREET
FSAIEE | PMIITPSA | FMIITSPA

## 1 FEBRUARY

1893 Thomas A. Edison finished construction of the first motion picture studio - the Black Maria in West Orange, New Jersey. The name Black Maria came from a slang term for police wagons, which were similarly cramped, uncomfortable, and dark.

## 2 FEBRUARY

1935 Leonarde Keeler, co-inventor of the polygraph machine, used the lie detector on two criminals in Wisconsin, who were later convicted of assault after the lie detector results were introduced in court.

## 3 FEBRUARY

1986 Time magazine reported on growing frustration with the slow development of software for use in the computer industry. Philip Elmer-DeWitt reported about the delay in Microsoft Corporation's new Windows operating system. Silicon Valley pundits had taken to calling such software "Vaporware".

## 4 FEBRUARY

1946 Sir Herbert Baker, architect of buildings such as the Union Buildings and Groote Schuur Hospital, died in London at the age of 83.

## 5 FEBRUARY

1952 The first "Don't Walk" sign was installed in New York City. The installation of this sign was inspired by the growing number of deaths resulting from pedestrian accidents.

## 6 FEBRUARY

1910 Belgian aviator Albert Kimmerling gave a successful flying display in Johannesburg. This event marked the start of serious aviation in South Africa.

## 7 FEBRUARY

1958 The Dutch car DAF 600 was introduced at the Amsterdam Motor Show. It would have been an altogether unremarkable car except for the fact that it was one of the first cars to offer an automatic transmission at an affordable price.

## 8 FEBRUARY

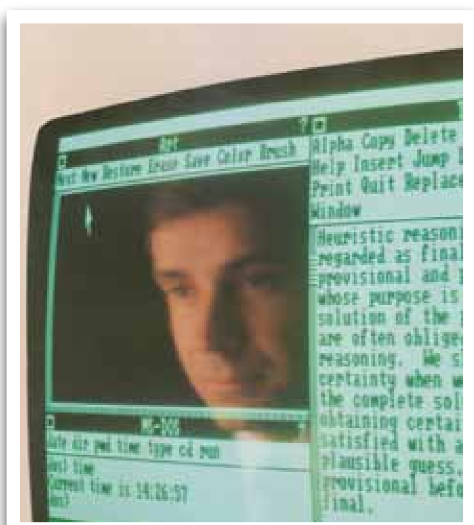
1945 C.D Lake, H.H. Aiken, F.E. Hamilton, and B.M. Durfee filed a calculator patent for the Automatic Sequence Control Calculator, commonly known as the Harvard Mark I. The Mark I was a large automatic digital computer that could perform the four basic arithmetic functions and could handle 23 decimal places. A multiplication took about five seconds.

## 9 FEBRUARY

1963 The first flight of the Boeing 727 occurred. For over a decade, it was the most produced commercial jet aircraft in the world.

## 10 FEBRUARY

1996 IBM's Deep Blue chess computer defeated world champion Garry Kasparov. No computer had




ever won a game against a world champion in chess. Kasparov would eventually win the series 4-2.

## 11 FEBRUARY

1966 The RAND Corporation (an American nonprofit think tank) took the Johnniac Open Shop System (JOSS) out of service. JOSS was a conversational time-sharing service in which long delays existed between sending information to the computer and getting results back.

## 12 FEBRUARY

1851 Edward Hargraves announced he has found gold in Bathurst, New South Wales, Australia, which started the Australian Gold Rush.

## 13 FEBRUARY

1895 The Lumiere brothers patented their cinematograph, one of the earliest motion picture projectors, which also served as a film camera and developer, making it one of the first "all-in-one" devices, beating HP by about 100 years.

## 14 FEBRUARY

1924 The Computing Tabulating Recording Corporation was renamed International Business Machines, aka IBM.

## 15 FEBRUARY

1995 President Nelson Mandela revealed he would not be standing for re-election in 1999. When Mandela finally retired in 2004, he said the now famous words: "don't call me, I'll call you."

## 16 FEBRUARY

1858 The first ironing board was patented by William Vandenburg and James Harvey. (There are many who consider this one of the most important inventions of all time.)

## 17 FEBRUARY

1994 Apple launched their QuickTake 100 digital camera, one of the very first digital cameras aimed at the consumer market. Unfortunately for Apple, as seemed to be a problem for them at the time, they didn't execute the marketing for this device very well which allowed other companies to take the lead in the digital camera market. Apple was out of the digital camera market by 1997.

## 18 FEBRUARY

1946 Television signals were first successfully transmitted from Washington D.C. to New York City over an AT&T coaxial cable. *And you thought cable TV was invented in the 1980s!*

## 19 FEBRUARY

2008 The "war" over the High Definition successor to the DVD ended when Toshiba announced it would discontinue its HD DVD format.

## 20 FEBRUARY

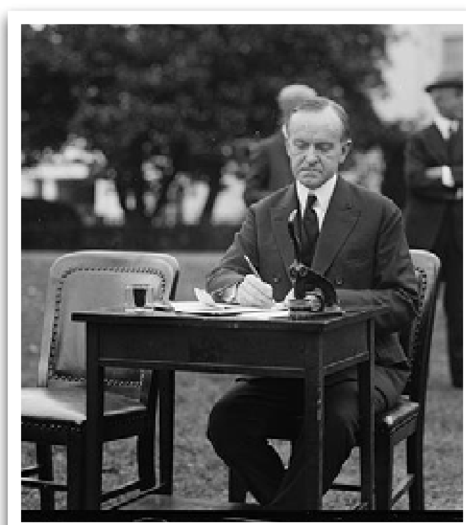
1947 Computer pioneer Alan Turing suggested that artificial intelligence be tested using the game of chess during a lecture to the London Mathematical Society. Computers, he argued, like humans must be given training before their IQ is tested. Human mathematicians have always undergone extensive training; and this training is similar to putting instruction tables into a machine, he said. Therefore one cannot expect a machine to build up a set of instruction tables on its own.

## 21 FEBRUARY

1858 The first electrical burglar alarm was installed by inventor Edwin T. Holmes in Boston, Massachusetts.

## 22 FEBRUARY

1924 The first US presidential radio address was delivered by Calvin Coolidge. It was broadcasted from the White House, on five stations to an estimated five million listeners.

# FEBRUARY

*continues from page 63*

## 23 FEBRUARY

2005 It was announced that a total of 21 000 driving licences would have to be cancelled after a former Limpopo traffic officer, M.S. Pela, appeared in court on more than 900 charges.

## 24 FEBRUARY

1968 The Rand Afrikaans University opened for learning in Johannesburg.

## 25 FEBRUARY

1965 The Roman Catholic Church's Archbishop of Cape Town, Owen McCann, an enemy of Apartheid, became South Africa's first Cardinal when he was invested by Pope Paul VI in St Peter's Basilica.

## 26 FEBRUARY

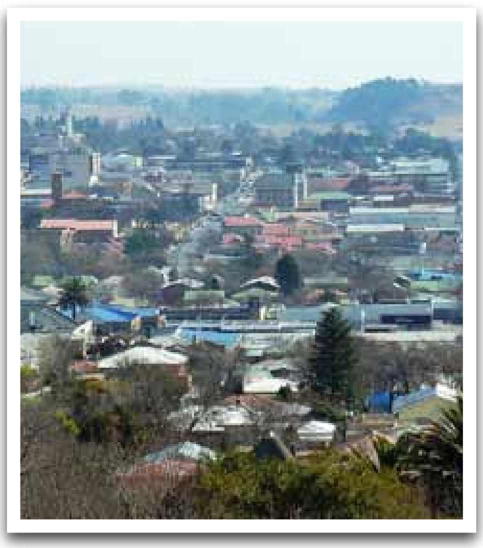
1935 Scottish physicist Robert Watson-Watt, considered by many to be the inventor of RADAR (RAdio Detection And Ranging), first demonstrated its feasibility. Watson-Watt had been experimenting using radio waves to locate thunderstorms and thought of the idea of using it to detect aircraft. Watson-Watt lead the demonstration where signals from a BBC short-wave transmitter were bounced off a Handley Page Heyford aircraft at Daventry, England. This technology entered service in 1938 under the code name Chain Home and provided the vital advance information that helped the Royal Air Force win the Battle of Britain.

## 27 FEBRUARY

1864 The town of Bethlehem was founded in 1864 *(other sources claim 1869)*. It is nestled in the Maluti Mountains in the Free State Province and is one of the towns that grew rapidly after it was founded. The rapid growth was due to the town being connected to Johannesburg, Harrismith and Bloemfontein by rail. The town's name is of Hebrew origin and means "house of bread", and it was so named as the town has fertile land where wheat grows in abundance.

## 28 FEBRUARY

1954 The first colour television sets, using the National Television System Committee's (NTSC) standard went on sale to the general public. NTSC was the standard used in most of North and South America, Japan, and a few other places in the world wn



MARCH I APRIL 2018

## MARCH 2018

| | | | |
|---|---|---|---|
| 4 - 6 | 11th International Symposium on Mechatronics and its Applications | United Arab Emirates | www.ieee.org.za |
| 5 - 6 | Fundamentals Of Developing Renewable Energy Plants | Johannesburg | roberto@saiee.org.za |
| 7 - 9 | West Africa Power Summit | Senegal | www.africa-energy.com |
| 6 - 9 | Advanced Microprocessor Based Power System Protection | Johannesburg | roberto@saiee.org.za |
| 13 | SAIEE Charity Golf Day | Glenvista, Johannesburg | geyergsaiee.org.za |
| 13 - 14 | Design Of Economical Earthing Systems For Utility Electrical Installations | Johannesburg | roberto@saiee.org.za |
| 15 - 16 | ARC Flash | Johannesburg | roberto@saiee.org.za |
| 15 - 17 | 2018 10th International Conference on Computer Supported Education | Portugal | www.ieee.org |
| 20 - 22 | 2018 35th National Radio Science Conference | Egypt | www.ieee.org |
| 21 - 22 | 4th Africa Mini Grids Summit | Nairobi - Kenya | www.africa-energy.com |
| 27 | SAIEE AGM | Johannesburg | www.saiee.org.za |
| 27 - 28 | Power & Electricity World Africa 2018 | Johannesburg | www.terrapinn.com |
| 28 - 30 | 2018 IEEE 4th Middle East Conference on Biomedical Engineering | Tunisia | www.ieee.org |

## APRIL 2018

| | | | |
|---|---|---|---|
| 9 - 10 | IOT Standards and Applications | Johannesburg | roberto@saiee.org.za |
| 11 - 12 | Advanced Microsoft Excel for Engineers | Johannesburg | roberto@saiee.org.za |
| 11 - 12 | Africa Investment Exchange: Gas | Cape Town | www.africa-energy.com |
| 17 - 20 | Managing Projects Efficiently | Johannesburg | roberto@saiee.org.za |
| 18 - 19 | Incident Investigation and Management | Johannesburg | roberto@saiee.org.za |
| 24-25 | Photovoltaic Solar Systems | Johannesburg | roberto@saiee.org.za |

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## Gauteng Central Centre
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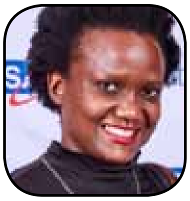
**T**|+27 11 800 4475 **E**|CornelTG@eskom.co.za



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