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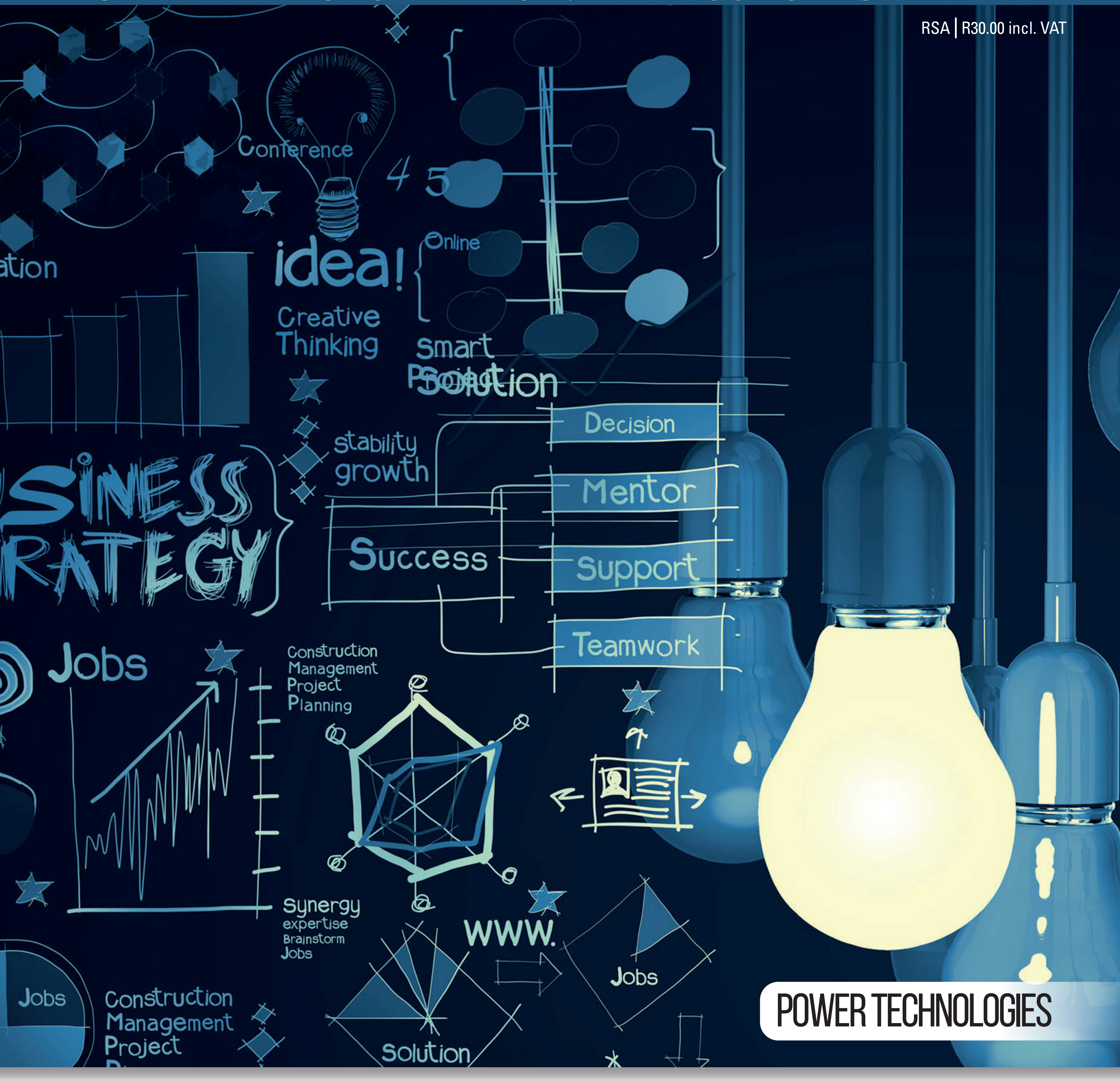

POWER TECHNOLOGIES

SAIEE THE OFFICIAL PUBLICATION OF THE SOUTH AFRICAN INSTITUTE OF ELECTRICAL ENGINEERS | JANUARY 2020

ACTOM HIGH VOLTAGE EQUIPMENT COMPLETES R22-MILLION GENERATION TRANSMISSION INTERFACE CONTRACT FOR ESKOM'S KUSILE POWER STATION.

ACTOM High Voltage Equipment was awarded a R22-million contract for the generation transmission interface for all six generation units at Eskom's new Kusile power station currently under construction near Emalahleni in Mpumalanga.

The contract, involving the supply and erection of 400 kV transmission lines from each of the six generation units to the nearby transmission substation that will link the new power station to the national electricity grid, was awarded to the division in mid-2015.

The contract also included supplying and erecting galvanised steel cross-beams, which are to be installed between each of the generation units to support the transmission lines strung across to the transmission substation.

The contract follows the award to ACTOM High Voltage Equipment in mid-2012 of the generation transmission interface contract for Medupi, Eskom's other new coal-fired power station, near Lephalale, Limpopo Province.

ACTOM High Voltage Equipment has successfully completed erection of the transmission lines and associated equipment linking Kusile's Generation Units to the transmission substation. It was completed as scheduled.

HIGH VOLTAGE EQUIPMENT
A division of ACTOM (Pty) Ltd

ACTOM

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Dear Valued Reader

We are at the end of the first month of 2020 - where has it gone? To all our readers, welcome to 2020.

Our very first issue of 2020, focusses on Power Technologies. Our first feature article, on page 18, "A Novel Dual Input High-Step up DC-DC Converter with One Bi-directional Port for Renewables" discusses how a new dual-input high step DC-DC converter is developed. The structure of the proposed converter consists of one unidirectional and one bidirectional port.

The second feature article, asks the questions: Will the global energy transition from fossil fuels to sustainable energy be gradual or rapid? A paper from the World Energy Forum discussing the speed of the global Energy Transition. Find it on page 26.

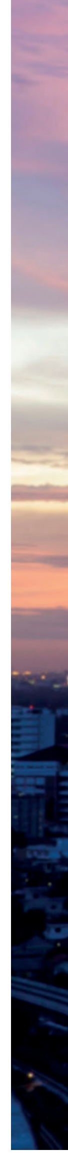
The China-based monopoly of high-energy permanent magnet materials, used in modern wind generators, impact the economic viability and local content value of most wind turbines installed in South Africa, especially in large installations. I share with you a paper on "Potentials of locally manufactured wind generators in SA" - find it on page 50.

If you are looking for a 24/7 service partner for electrical and mechanical rotating machines, look no further than the information on page 61.

Herewith the January issue, enjoy the read!

Minx

DRONES Benefit or Curse?



GEORGE DEBBO
2019 SAIEE PRESIDENT

During the past few weeks two incidents occurred which got me thinking about the use of Drones and whether such technology has added value to our lives or created a curse.

The first incident involved the killing of Iranian General Qasem Soleimani on 3rd January 2020 when the United States military used a drone strike that attacked the General's car convoy near the Baghdad International Airport. Although the General was the prime target the drone attack killed 10 individuals including Soleimani.

The use of drones or Unmanned Aerial Vehicles (UAVs) has been around for many years within the military. They are predominantly used in situations were manned flight is too risky or difficult. A drone strike uses one or more of these UAVs in an unmanned manner in order to attack a predetermined target. The attack usually involves the firing of a missile or the release of a bomb at the target. The drone can be equipped with different weapons systems including guided bombs, cluster bombs, incendiary devices, air-to-air missiles, air-to-service missiles, anti-tank guided missiles or any type of precision guided ammunition.
Since the early 2000's most of the drone strikes have been carried out by the USA Military in countries such as Afghanistan, Pakistan, Syria, Iraq, Somalia and Yemen using air-to-service missiles. However, other countries are also known to have manufactured operational UAVs; these included Israel, China, Iran, Italy, India, Pakistan, Russia, Turkey and Poland.

One area of research and development work at present is to design anti-UAV systems that can be used to counter the threat of drone strikes. However, developing such system is proving difficult and the reason for this is because of the legislation and regulation that is currently being applied in order to protect against consumer drones. An article recently appeared on the Defenceone.Com website stated that if you bought and deployed all of the emerging counter drone technologies available today within the USA, you would be in violation of up to two dozen different US Laws dealing with everything from privacy to communication channels to aircraft interdiction.

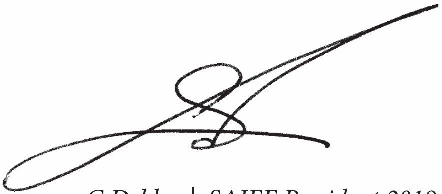
The second incident occurred much closer to home. We have recently relocated to the coast and shortly after New Year one of our new neighbour's test drove a

new recreational drone that he must have received, I assume, as a Christmas gift. This was even though the rules for the Estate in which we live prohibit the use of drones. He flew the drone from his front porch out over the sea for some way and then turned it around and brought it back for a perfect landing at his feet. He repeated this manoeuvre a few times and as I watched, thinking about the Soleimani incident which had used a drone, I began thinking about the positive benefits that drones have made to our lives. Besides recreational value drones are also significantly contributing to other parts of our lives. For example, drones are currently being used extensively in the agricultural environment to detect areas where crops have been affected by weeds to target the use of herbicides rather than "blanket bombing" crops with herbicides as was done in the past.

Drones are also being used in populated areas in order to deliver parcels, to assist in the maintenance of buildings and other civil infrastructure and in the filming of sports events like marathon. For example, in conjunction with using 5G mobile technology for communications, drones were used during the 2018 Winter Olympics in PyeongChang South Korea in order to provide live television images of the skiers as they raced down the slopes. A record-breaking formation of 1200 drones were also used during the opening ceremony in order to create a constellation of LED lights in the night sky above PyeongChang Medal Plaza.

Drones can also be used to provide safety at large events by monitoring and controlling crowds, and they can provide valuable support to police, security and fire services. They can also be of valuable assistance during sea search and rescue operations, as the sea can be viewed above if someone is lost at sea drones can search for them very quickly and efficiently.

So, as can be seen from the few examples that are described above, drones do provide valuable support to our daily activity in many areas and therefore can definitely be considered a benefit to the human race even if on occasion they used to carry out operations, military or otherwise, that not everyone would agree with.



G Debbo | SAIEE President 2019
Pr. Eng | FSAIEE

'ENGINEERS OF CHANGE' HONOURED AT SAIEE 2019 ANNUAL AWARDS

Excellence in engineering was in the spotlight as the South African Institute of Electrical Engineers (SAIEE) "celebrated visionaries, the engineers of change" at the 108th SAIEE Annual Awards Dinner held at the Sandton Convention Centre in Johannesburg last week.

The black-tie event, which coincided with the organisation's inaugural national conference, honoured the best in the industry for their contributions to the sector.

Guest speaker, Saray Khumalo, the first black African women to reach the summit of Mount Everest, received a standing ovation as she shared her journey of courage and perseverance.

Surprise act, Arias Anonymous, delighted guests as the duo transformed from chef and manager to a singing sensation, serenading the crowd with classic arias.

Jacaranda FM's Scenic Drive with Rian presenter, Philicity Reeken, brough her signature energy as the MC and was joined by SAIEE's President and CEO, George Debbo and Sicelo Xulu, during the awards ceremony. The recipients in six award categories, including the winners of the SAIEE National Students Project Competition, was announced.

SAIEE ENGINEER OF THE YEAR

MONDE SONI

Sponsored by Actom, the award recognises an engineer who energetically works towards promoting electrical science for the benefit of the Southern African community.

Soni, a senior planning engineer at Eskom, facilitated the establishment of the SAIEE

[from left] Monde Soni, Casbah Zwane (Actom) and George Debbo (SAIEE).

Load Research Chapter. He wrote a paper for CIGRE SA on "Bulk Energy Integration Studies" – a relatively new subject internationally and more particularly in developing countries. His methodology for bulk energy storage modelling and simulation is considered the first to be developed in South Africa. He currently also serves as an SAIEE Council Member on the institute's education and technology & knowledge leadership committees.

SAIEE ENGINEERING EXCELLENCE AWARD

TC MADIKANE

Sponsored by Fluke, the award honours an individual who excels in electrical engineering and demonstrates above-average participation in the SAIEE and its activities.

Madikane is a highly respected engineer with more than 24 years' experience in the industry. He heads up his own engineering company, Igoda Projects, that is celebrating its 20th anniversary this year. Madikane has a long history with the SAIEE, joining the institute as the Student Chapter Chairperson while he was studying at the then University of Natal (now University of

[from left] Francesco Pagin (Fluke), George Debbo (SAIEE), TC Madikane.

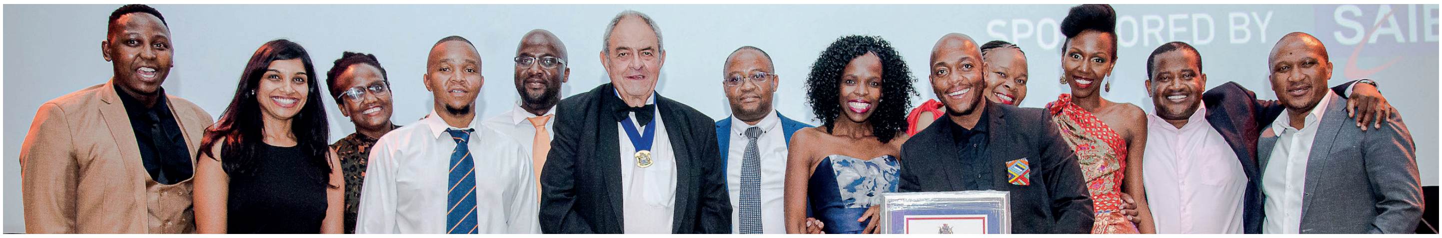
KwaZulu-Natal). In 2006, he was crowned the SAIEE Engineer of the Year Award. Madikane's contribution and involvement in the SAIEE never ceased throughout the year and he was eventually appointed as the SAIEE President in 2016.

SAIEE WOMEN IN ENGINEERING AWARD

BERTHA DLAMINI

[from left] Sicelo Xulu (SAIEE), Bertha Dlamini and George Debbo (SAIEE).

A new category of the awards, it seeks to recognise an individual for her contribution to promoting and inspiring women in engineering.



Dlamini needs no introduction in the industry as a passionate advocate for the accelerated participation of African women and youth in Africa's power and energy sector. Using her vast network, she mobilises global stakeholders to work together to break down the barriers for women and young people in the industry. She is currently the President of African Women in Energy and Power (AWEaP). She has also been a strategic advisor to the Association for Municipal Electricity Utilities (AMEU) where she played a critical role in advancing gender mainstreaming in South Africa's energy sector.

SAIEE PRESIDENT'S AWARD

STANLEY BRIDGENS

[from left] Sicelo Xulu (SAIEE), Stanley Bridgens and George Debbo (SAIEE).

This prestigious award recognises the significant contributions of an engineer to the sector and is selected by the SAIEE President.

Bridgens has made a massive contribution to the electricity supply industry over the course of his long career. He's a Fellow and Past President of the SAIEE, serving as a member of the institute for over 54 years. He started as an apprentice electrician in 1959 at the then Johannesburg Electricity Department (now City Power) and left after 43 years as the utility's director. He is recognised as a pioneer in the early implementation of a pre-payment metering philosophy. After he retired, he joined the SAIEE's administrative staff and introduced much-needed financial management and governance processes and procedures that the institute still uses today.

KEITH PLOWDEN YOUNG ACHIEVER

MICHELLE GOVENDER

[from left] Michelle Govender, George Debbo (SAIEE) and Adolf Erasmus (SGB-SMIT POWER MATLA).

Sponsored by SGB-SMIT POWER MATLA, the award recognising the most outstanding young achiever in electrical or electronic engineering of the year.

Govendor is a force to be reckoned with as an Engineering Council of South Africa (ECSA) registered engineer and cybersecurity specialist for the World Bank-CIGRE African Utilities Initiative. She also serves an advisor for the Electricity Power Research Institute (EPRI) and as a member of the SABS SC 27 Technical Committee. Govender is passionate about connecting the youth with the engineering industry and is currently working on an initiative to connect aspiring founding engineers who are keen to start their businesses with South African engineers and CEOs.

SAIEE CENTRE OF THE YEAR

SAIEE CENTRAL GAUTENG CENTRE

This award, which was introduced as a new category in 2018, seeks to honour the best among SAIEE's centres, recognising their contributions to the institute and the engineering profession. See photo above.

SAIEE NATIONAL STUDENTS PROJECT COMPETITION

DESWILL WILLEMSE & KAI GOODALL

[from left] Kai Goodall, George Debbo (SAIEE) and Deswill Willemse.

Final year electrical, electronic and computer engineering students from academic universities and universities of technology compete to complete an intensive design project as part of the competition every year.

Engineering students, Deswill Willemse from the Cape Peninsula University of Technology (CPUT) and Kay Goodall from the University of Cape Town (UCT) beat out 15 other students with their final year projects. The pair was flown up to Johannesburg to accept their prizes in person.

Point and Shoot Laser Distance Meter

COMTEST is pleased to announce Fluke's new 417D, an accurate, durable, point and shoot laser distance meter, designed for indoor and outdoor, dusty and wet conditions.

The easy, one-button operation means users can minimize time taken by measuring, while the Fluke brand assures the quality and reliability of measurements taken. And, with simple function buttons, three different measurement tasks can be completed quickly and easily. The extra bright laser is clearly visible, so the target point can always be seen, even if the target object is in a hard-to-reach spot, or at a long distance. The 417D has a large 2-line illumi¬nated LCD screen and three-buttons for easy-to-use one-handed measurements.

417D'S FEATURES AND BENEFITS:

- Measures up to 40 m (accuracy of 2 mm)
- 1 button instant distance measurement
- Quick calculation of area (square meters)
- Continuous measurement capable
- Battery life 3 000 measurements and improved by 'auto shut-off'
- 1-meter drop tested
- IP54 dust and water resistant
- 3-year warranty

Contact COMTEST for more information on Fluke's 417D laser distance meter, or for upcoming seminars, demos or to locate the nearest dealer, on 010 595 1821 or sales@comtest.co.za

Dust extraction specialist announces attendance at UK's premier event

Dustcontrol UK is set to exhibit its range of high-performance extraction equipment at the eagerly anticipated Southern Manufacturing & Electronics 2020 Exhibition.

Taking place from 11 - 13 February at the Farnborough International Exhibition and Conference Centre, Hampshire, the Dustcontrol team will be showcasing the firm's extensive range of both fixed and mobile cyclone-based dust extractors and air cleaners at Stand A1028.

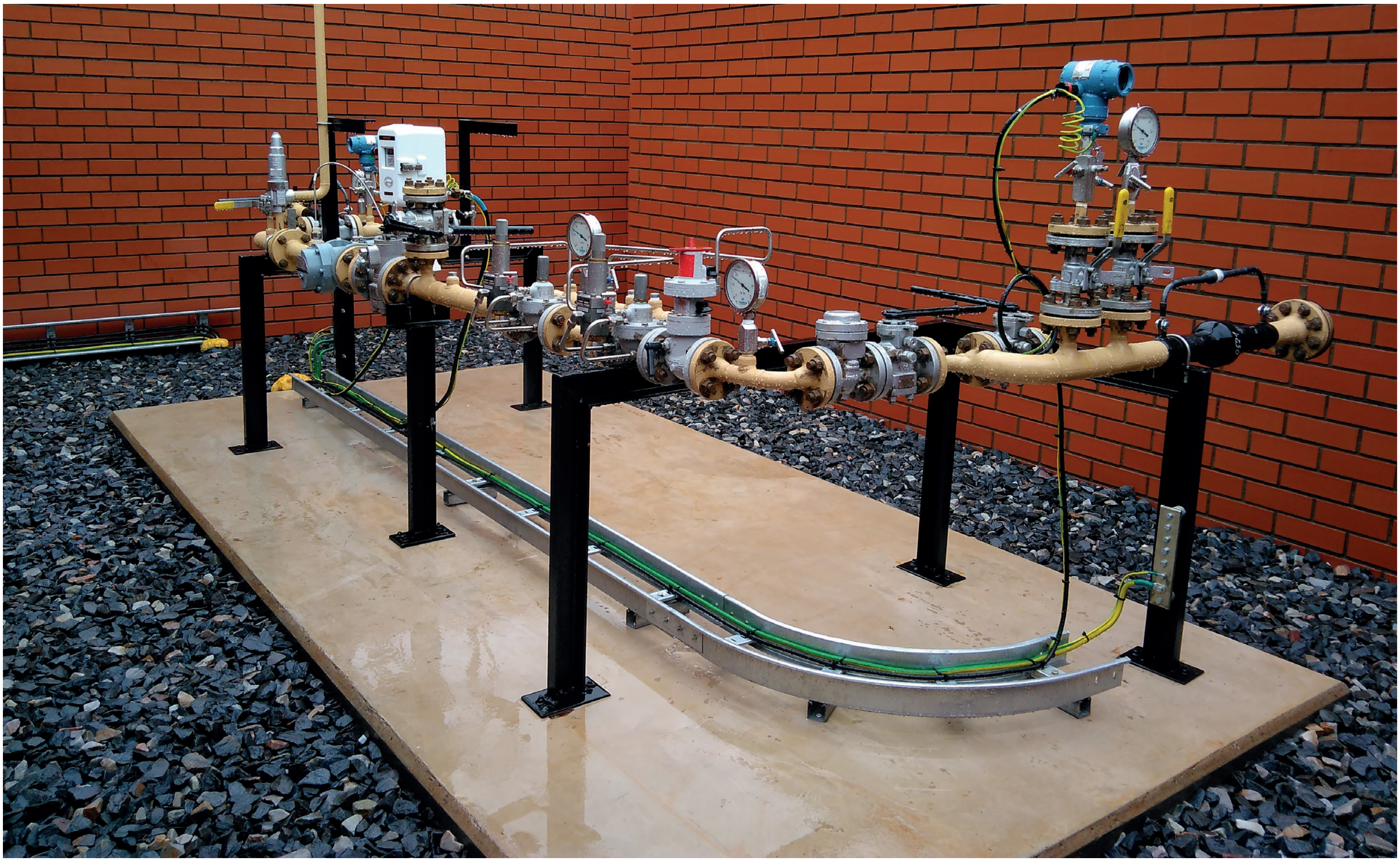
The DC11-Module for example, which comes in several models, is an optimised stand-alone unit for source extraction and industrial cleaning. It has been designed to service up to six normal extraction points or several cleaning outlets at a time and is modularly built, meaning it can be tailor-made to suit any manufacturing and production environment.

As with all of Dustcontrol UK's equipment, the DC11-Module can be fitted with HEPA 13 filters, meaning exhaust air can be safely returned to the work environment.

James Miller, Managing Director of Dustcontrol UK, said: *"The Southern Manufacturing & Electronics Exhibition promises to be another exciting event for those in the industry. The exhibition will provide us with an excellent opportunity to show the manufacturing and electronics industry how we can help businesses stay healthy through the use of efficient dust extraction."*

For further information on Dustcontrol UK, visit www.dustcontroluk.co.uk

Ice-cream factory switches from coal boilers to HPCMS station



An ice-cream factory has replaced its old coal-fired boilers with more efficient and 'green' natural gas fired boilers.

When looking for an efficient solution to switch from its old and inefficient coal fired boilers, an ice-cream factory looked for a trusted product from a reputable supplier. Egoli Gas supplied the factory with an HPCMS (High Pressure Customer Metering Solution) which was acquired from Energas Technologies, a leading supplier of high-end and specialised equipment to the oil and gas industries in Africa. The factory will benefit from the more efficient and environmentally-friendly natural gas fired boilers.

Energas is a specialist supplier of complete skid-mounted HPCMS for natural gas. According to Laetitia Jansen van Vuuren, Technologies Product Engineer at Energas Technologies, natural gas is a very reliable, safe and cost-effective solution for industrial users, compared with other conventional sources of energy such as electricity, diesel, coal or LPG. *"Natural gas can be supplied via a pipeline network or by means of compressed natural gas cylinders to users not in the vicinity of a pipeline,"* explains Jansen van Vuuren.

She adds that these skid-mounted units supplied by Energas offer an array of benefits: the single source reduces client man-hours spent; the pre-packaged factory-built skids cost less than individual equipment and piping construction and installation on site; these units reduce field construction time and overall project schedule; a complete factory test is conducted before shipment, which reduces risk; the units are easy to install in remote areas; and customers have peace of mind as a result of single source accountability.

The skid-mounted stations from Energas Technologies are designed, shop-fabricated and assembled, fully-tested and packaged before transported to the site. The skid includes filtration, pressure reduction, over-pressure protection and metering. The station will reduce the pressure from 35 bar (inlet line pressure) down to 1 bar (outlet pressure to the user) within one stage of pressure reduction.

"The station has a single run and has a flow capacity of 200 Sm3/h. A second run can be added for redundancy if required. The station includes the skid frame, piping, insulation joints, pressure regulator valve, slam-shut valve, pressure relief valves, gauges and isolation valves. The station is designed according to ASME B31.3," concludes Jansen van Vuuren.

INDUSTRYAFFAIRS

World Energy Council publishes new research outlining necessary steps for progress in energy storage

The World Energy Council has published its latest Insights Brief with the launch of Innovation Insights Brief: *"Five Steps to Energy Storage"*. Developed in collaboration with the California Independent System Operator (CAISO), the Brief outlines the steps necessary to enabling progress in the deployment of energy storage.

The Brief contains exclusive information on the current state-of-play of energy storage and showcases 10 case studies focused on a the latest technologies being deployed across varied geographies, providing actionable insight based on lessons learned and concrete examples of new developments in the energy storage space.

The Council's research shows that, whilst there is plenty of visionary thinking, recent progress has focused on short-duration and battery-based energy storage for efficiency gains and ancillary services. There is limited progress in developing daily, weekly and even seasonal cost-effective solutions which are indispensable for a global reliance on intermittent renewable energy sources.

In response, the Brief includes an actionable five-step approach to enabling energy storage and truly capturing its potential as a flexibility tool. Working with its global network, the Council will convene interactive workshops to further test and accelerate the adoption of this approach.

Steve Berberich, CEO, CAISO said: *"The Energy Storage Brief is an enormously powerful outline of the value of storage and the regulatory and market opportunities that need to exist for it to truly flourish."*

Dr Angela Wilkinson, Secretary General of the Council said: *"Energy storage is a gamechanger and this innovation brief highlights the reality that we need new and different storage pathways to enable better lives and a healthy planet. It is time to look beyond battery technology innovation and enable new policies on storage and its roles as an energy resource, an enabler of whole systems reliability and accelerator the global energy transition."*

Economical magnetic-inductive flowmeters

INSTROTECH now offers Kobold's MIK, a compact, magnetic-inductive flowmeter, combining a large measuring range, from at 0.01 l/min and currently to 700 l/min, and six different measuring tube sizes, from G ½ male to G 2 ¾ male; perfect for users with smaller to medium-sized measuring ranges. MIK measures the flow rates of electrically conductive liquids with a high degree of precision and is not influenced by the medium or its material characteristics (density, viscosity, or temperature). Particular advantages include uninterrupted flow of the medium, no moving parts, and installation in any position desired.

MIK has various material combinations for different media in the chemical industry. Flow housings are available in PPS with stainless steel electrodes and PVDF with Hastelloy electrodes. For extremely aggressive liquids, a combination of PVDF and Tantalum is used. A variety of seals are available in NBR, FPM, or the highly chemically resistant FFKM. Installation is quick and easy thanks to practical material-specific connection possibilities, such as PVC glue-in, stainless steel weld-on or PVC hose connections.

Characteristics include:

- Range from liquids, acids and caustic solutions: 0.01-0.5 ... 36-700 l/min
- Accuracy: +2.0% of full scale
- Pressure max: 10 bar; Temp max: 80 °C
- Advantages: no moving parts in the measuring tube; low pressure loss; any mounting position; short reaction time (a replacement for calorimetric flow switch)

MIK applications include the monitoring of additives or cooling agents, totalizing, or batching, the devices which use the magnetic-inductive principle of measurement, are an optimum and cost-effective solution. Matching electronics are offered for various tasks, from designs with only switching or analogue output to those with counting and dosing electronics.

Quick Repair Puts Arcelormittal Turbine Generator Back To Work

ACTOM Turbo Machines technicians (from left) Louis Claasen, Jacques Zandberg and Dehan Meyer prepare to work on the 19 t rotor of the 40 MW turbine generator, as a rigger guides it into position.

A 40 MW turbine generator from ArcelorMittal's Vanderbijlpark works was repaired on a fast track schedule by ACTOM Turbo Machines.

The emergency repairs were required after the generator broke down in October 2018, with damage including failed bearings on the generator train. ACTOM Turbo Machines, a division of ACTOM (Pty) Ltd, undertook to complete the work and have the generator back in operation by mid-December 2018.

Demonstrating its high level of expertise as a mechanical repairer, ACTOM Turbo Machines first diagnosed all the elements that would require attention during the repair. All four bearings – as well as the rotor sealing elements – were found to be damaged. Other damage, which was unrelated to the October failure, was also discovered.

"The damage involved a crack on the high-pressure (HP) gland section of the main steam casing, while a second unforeseen irregularity was a malfunction in the starting or auxiliary oil pump," Danie Bloem, ACTOM Turbo Machines' project manager on the contract, says.

Other irregularities were an incorrect bolt clearance on one of the HP palms, probably due to faulty installation.

"In addition to repairing the damaged bearings, we also had to recondition a spare set of bearings that ArcelorMittal had in reserve," Bloem says. *"The sealing segments were replaced with new ones manufactured at our Sasolburg works."*

He notes that the process of repairing the crack in the main steam casing took the team five days, working around the clock.

"A high level of welding expertise was required here, as the casing is made of a special material," he adds.

The repair of the starting oil pump was also performed in only two days. This required the manufacture of a new shaft, and also the reconditioning of the mechanical seals.

Once the generator resumed operation, vibration testing confirmed that its performance had improved significantly, Bloem points out.

Pragma invites engineering students to apply for its acclaimed 3-week Student Training Programme

Leading enterprise asset management engineering company Pragma, will again host its award-winning Student Training Programme (STP) in June and July 2020 at its head office in Cape Town. Students are invited to apply for one of the ten sought after spots on this programme between 1 March and 31 March 2020.

Says Stéphan Pieterse, Chief People Officer at Pragma: *"The three-week programme is specifically aimed at B.Eng. or B.Sc.Eng. (Industrial, Mechanical, Electrical, Electrical and Computer or Mechatronic) students in their third or fourth year of studies. The content of the programme ensures that students are introduced to the concepts of enterprise asset management as well as Pragma's service offering. Furthermore, participants also have the opportunity to be part of various coaching and mentoring sessions with Pragma's senior management team in order to provide them with valuable life and career lessons."*

According to Darius Booyens, Associate Consultant at Pragma, the theme will be Data Science | Future-proof your career. Booyens explains: *"Data Science is a regular topic within Pragma. It goes hand in hand with connected tech - another big drive within Pragma. I personally believe that data science will go from being a wanted skill to a necessary skill in the near future, especially considering the incredibly fast expansion and use of technology in the physical asset management space. The era of connected devices and big data is upon us and if we (the proverbial employer and employee) aren't ready, we'll be left behind. The ability to do complex problem solving is the top skill needed in jobs going into 2020 and beyond. To future proof your career is extremely important if we look at the pace at which new jobs are created and traditional ones come to an end. Data science and machine learning will help us become better at our jobs so that we can be more efficient to keep up with market demands."*

Nina Booysen, Project Engineer at Pragma, adds that the student training programme typically runs from the start of the last week in June to the end of the second week in July, i.e. fifteen working days. *"The programme will run from the 22 June until 10 July 2020. This year we celebrate a decade*

of Pragma's Student Training Programme (STP), which also coincides with Pragma's 30th birthday! We'll aim to reunite our Pragma STP Alumni at this momentous occasion. 2020 ought to be a big year for the Pragma STP, and will prove to demonstrate the impact that the programme has had on the lives of the Alumni."

Pieterse explains that Pragma has a very thorough and intensive student selection process.

"We look at practical skills and knowledge, soft skills (presentation skills), and personality tests. By looking at all of these criteria, we're able to filter through hundreds of applications and identify talented individuals from a myriad of universities. Many of these individuals end up working for Pragma and become great assets and team mates at the company. Both Darius and Nina participated in the programme. We only consider university students for the STP. Pragma has other opportunities available for non-university students. Please refer to our website."

Pieterse concludes: *"It's been an amazing privilege and honour to have been part of the design and execution of this programme since the very first one presented back in 2011. Over the last nine years, I've seen a tremendous amount of growth in the individuals we worked with and I know that many of them are making a lasting impact at the companies they work for. We've also experienced that impact at Pragma. It's time for me to hand over the reins and who better to take over than two STP alumni's! I wish Darius Booyens and Nina (nee Van Rooyen) Booysen all the very best. I know they will take the programme to even greater heights!"*

Launched in 2011, the programme has been an enormous success and has won various industry accolades. It excelled at the 2015 Skills Development Summit, winning in all three categories the programme was nominated in, including Best Graduate Training Programme, Best Training Programme Large Company and Best Innovative Training Programme. Further to this, it won first place at the 2019 Skills Development Summit as Best Graduate Training Programme and was a finalist in the Best Training Programme Large Company and Best Innovative Training Programme categories. The Student Training Programme was also a finalist in the Best Graduate Development Programme at the 2019 Future of HR Summit.

With limited space available, interested students are urged to apply as soon as the application window is open at https://www.pragmaworld.net/culture-careers/student-training-programme/ by 1 March 2020.

For further info, visit www.pragmaworld.net. wn

CIGRE COLLOQUIUM FEEDBACK

INDIA - NOVEMBER 2019

Sharon Msuhabe, Nishal Mahatho & Khayakazi Dioka representing the Southern African National Committee of Cigre.

Dr Ralf Pietsch (at the podium) and Dr Jens Seifert (seated) during the D1 Tutorial session.

Entrance into the HVDC Multi-terminal station.

A joint A2, B2 and D1 CIGRE Colloquium & Tutorials event was held in New Delhi, India from the 18th - 22nd November 2019. Southern Africa was represented by Ms Khayakazi Dioka (A2 – Transformers & Reactors), Ms Sharon Mushabe (B2 – Overhead Lines) and Mr Nishal Mahatho (D1 – Materials & Emerging Test Techniques). This article focuses on the Study Committee D1 related issues.

BY | NISHAL MAHATHO
SENIOR SPECIALIST
ESKOM & CIGRE D1 SA
REPRESENTATIVE

The week comprised of D1 working groups held by various conveners, the D1 Study Committee chaired by the international chair – Dr Ralf Pietsch and the main D1 Colloquium and tutorial session.

At the D1 SC meeting, there were a number of matters discussed:

- A large focus was on the upcoming Paris 2020 session. The idea of this year's Paris session is to promote more technical discussions. It was noted that there is an increase in the number of submissions, and this can be attributed to the inclusion of Distribution topics into Cigre.
- Dr Ralf Pietsch, on behalf of D1, has compiled a 30-page contribution to the Cigre Green book (The CIGRE Green Book provides the entire know-how about switches in a high voltage system).
- The matter regarding the use of Webinars was raised, and it was felt that more use should be made of these as a platform to share information, or to present some on-going work. The UK is using webinars successfully, in what they call "lunch-time-webinars".
- The South African National Committee was briefly discussed, and the initiative that is underway with the World Bank to fund tutorials, attendance at conferences, etc. for some of the other African countries. This is in an effort to create more collaboration with the other African countries as well as to spread the word of the Cigre technical work and to support these utilities.
- Feedback was presented by all the international convenors on the progress in their working groups. Nishal Mahatho, D1 SA rep, is also the convenor for a WG D1.61 entitled "Optical Corona Detection and Measurement. This group deals with the use of corona cameras for the location of electrical faults on powerlines and substations, and how their use or interpretation may be standardised, as there are currently no calibration standards or usage guidelines available. Nishal presented the progress made by the group – all of the round robin tests carried out by the international members have been completed, and the results are being collated and analysed, together with the limited experience from utilities. It is expected that this technical brochure will be completed by the first half of 2020.

The theme paper for the D1 technical session of the Colloquium, was presented by Dr BP Muni from India. Dr Muni spoke about the very large developments in India – the grid is growing at a rapid rate and as at

A presentation to the Cigre delegation by the station manager on a model prior to entering the HVDC station.

The iconic Taj Mahal in Agra.

October 2019, they were at 364 GW. There are many renewables projects currently on the horizon.. India has some of the largest HVDC developments in the world, but there is still much understanding required in this area and this creates much room for collaboration and research. There were three preferential subjects (PS) for the D1 Colloquium, viz. PS1 – Testing, Monitoring and Diagnostics, PS2 – Functional Properties and Degradation of Insulation Materials and PS3 – Insulation Systems of Advanced Components. There were 17 papers in the two day D1 session with 12 submissions being international and 5 from India. The theme for the technical session 1 was the Long Term Performance Insulation systems (AC & DC); technical session 2 focussed on Test Techniques for UHV (including HVDC), and session 3 contained papers relating to Advanced Diagnostic Techniques.

There were two D1 tutorials:

- Materials, Technologies, Testing and Diagnosis for Polymeric Overhead Line by Dr Jens Seifert. This tutorial was based on the work done as part of WG D1.27 and the TB 611. It covered aspects relating to polymer insulators, hydrophobicity, fingerprinting of materials and the different types of testing methods currently in use, and the new ones proposed.
- High Voltage On-Site Testing with Partial Discharge (PD) Measurements by Dr Ralf Pietsch. This tutorial was based on the work done in WG D1.33 and the TB 502. It covered aspects of high voltage sources and accessories for on-site applications, on-site pd measurements, pre-conditions for in-site testing and finally examples of test and measuring techniques for apparatus and systems.

Overall the SC meeting, WG sessions, Colloquium and Tutorials were a great success with high attendance, both locally and internationally. The Saturday following the Colloquium included a technical visit to a 6000 MW, 800 kV HVDC Converter Station in Agra, with a visit to the iconic and breath-taking Taj Mahal included! With the focus on the upcoming Cigre Paris Session in August 2020, the preferential subjects for D1 are:

PS1: TESTING, MONITORING AND DIAGNOSTICS

- Experience and insight from monitoring systems.
- Reliability of test equipment and systems for testing, monitoring and diagnostics.
- Data handling, analytics and advanced condition assessment.

PS2: FUNCTIONAL PROPERTIES AND DEGRADATION OF INSULATION MATERIALS

- New stresses, e.g. power electronics, load cycling, higher temperatures and compact applications,
- Materials with lower environmental footprint during production, operation, and disposal
- Characterization methods for validating functional properties.

PS3 : INSULATION SYSTEMS OF ADVANCED COMPONENTS

- Materials under high stresses e.g. field stress, flux, electric current and frequency.
- Experience and requirements for new test procedures and standards.
- Development of new materials, e.g. 3D printing, lamination, casting and additive or subtractive manufacturing.

As D1 SA we will need to provide some input into these preferential subjects, and begin with the compilation of presentations for the D1 session. D1 will only accept formal representation for discussion of PS, and will not entertain spontaneous contributions at this year's session. There are also three new working groups that have been proposed:

- D1.72: Test of material resistance against surface arcing under DC (D1 has proposed N Mahatho as a member).
- B1/D1.75: Interaction between cable and accessory materials in HVAC and HVDC (chemical interactions).
- D1/B1.75: Surface charges for HVDC cables.

D1 SA will need to consider our involvement in these groups, and put forward names of contributing members in the coming weeks. I also encourage anybody who is interested in joining any D1 working groups to please contact the author using the following email address: MahathN@eskom.co.za or 011 629 5341. wn

A Novel Dual Input High-Step up DC-DC Converter with One Bi-directional Port for Renewables

In this paper, a new dual-input high step DC-DC converter is developed. The structure of the proposed converter consists of one unidirectional and one bidirectional port. The bidirectional port is connected to a battery for energy balancing purpose. That is, the battery stores extra produced energy and releases stored energy in situations where there is a lack of energy.

BY | M A BAGHERPOURA, P FARHADIB N B HASSANLOUEIC

On the other hand, the bidirectional port is employed as the primary power source. The high step-up output voltage gain of the proposed converter makes it suitable for renewable energy applications where the output voltage is low. The proposed structure is superior over the previously proposed ones in terms of the number of components, energy interaction, simple configuration, and flexibility. The experimental results obtained in three different modes (i.e., without battery, with battery charging, and with battery discharging) are presented to verify the theoretical analysis and the performance of the proposed converter.

In recent years, due to the expanding use of renewable energy sources like PV, FC, wind, etc., designing new converters with appropriate control methods to reflect the variability of the resources is critical [4, 9]. Due to the characteristics of renewable energy sources, they need to be used in parallel with other resources. For example, photovoltaic (PV) panels are unable to supply load at night. Moreover, the rate of energy produced varies according to insolation and temperature. Most renewable energy output voltage is very low and variable. To deal with the problems mentioned above, most renewable energy resources need high step-up converters to run alongside them [11].

By increasing the efficiency of renewable energy sources, multi-input converters are introduced [2, 3, 6, 7, 12]. In [12], a dual input DC-DC converter is presented. One key benefit of this converter is individual control of the source to provide the desired voltage at the output and MPP (Maximum

Power Point) for inputs. An improved structure of a dual input DC-DC converter is introduced in [2]. Compared to [12] the proposed converter in [2] has better output voltage gain and resolves some of the drawbacks of the converters in [12]. The converters introduced in [3, 6, 7] are mostly modular with a high number of power sources and switches. In these circuit structures, each module uses an individual power switch for control. The power source's energy is transferred to load by a single inductor of the energy source.

As mentioned earlier, most renewable energy sources generate a low-value voltage. High gain DC-DC converters are offered in two primary groups, converters with coupled inductors and low numbers of circuit elements and circuits without coupled inductors with a high number of circuit elements. [8, 10] offer two high gain DC-DC converters, with and without using a coupled inductor. [8] presents a coupled inductor based high gain DC-DC converter. In this structure output, voltage gain can be changed by varying the transformer ratio. The proposed converter in [10] is a high gain DC-DC converter. In this circuit voltage gain is increased without using a coupled inductor, but the high number of power switches and circuit components can be viewed as drawbacks.

The recently proposed high gain multi-input DC-DC converter and PDFCM [1, 5] are suitable for use in renewable energy sources. The high step-up capability makes this structure flexible for use across ample voltage ranges. Also, by having a multi-input circuit, the efficiency of the converter is increased by making it reliable to use off-grid. In this paper, a high step-up multi-input DC-DC converter is proposed. In addition to the benefits that were mentioned for high gain and multi-input converters, the proposed converter consists of two ports, a unidirectional and a bidirectional. Having a bidirectional port provides an opportunity to use a battery in the converter structure to save extra produced power and to supply load when the generated energy is too low.

OPERATIONAL PRINCIPLES

Fig. 1 shows the circuit structure of the proposed converter. It consists of four power switches (S_1, S_2, S_3, and S_4), two diodes (D_1 and D_2), two capacitors (C_1 and C_2), magnetizing and leakage inductors (L_m and L_k), and load (R_{Load}).

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continues from page 19

The converter is operated in three operation modes:

1. Without Battery,
2. Battery Charging,
3. Battery Discharging.

Each mode operation is divided into sub-modes as described below.

WITHOUT BATTERY (MODE-I)

Operation sub-modes of the converter in mode one are depicted in Fig. 2. The equivalent waveform of the proposed converter in this mode is also shown in Fig. 3.

First Sub-Mode [t_0 – t_1]: This mode starts by turning on switches S_1, S_4 or S_2, S_3. Due to the difference in leakage and magnetizing inductors' current value, diode D2 conducts. Leakage and magnetizing inductors' current difference charge capacitor C_2 on the secondary side of the coupled inductor. Magnetizing inductor's current decreases due to the negative voltage on it, but the leakage inductor's stored energy increases.

Second Sub-Mode [t_1 – t_2]: This sub-mode starts when leakage and magnetizing inductors' stored energy become equal with each other and diode D_2 is turned off. This sub-mode lasts until the power switches turn off.

Third Sub-Mode [t_2 – t_3]: This sub-mode starts when the power switches turn off. In this sub-mode, the switches' parallel capacitors start to be charged by turning the power switches off. The capacitors continue charging until the switches' parallel capacitors voltage reaches capacitor C_1's. In this mode, the inductors' stored energy decreases and this mode finishes when diode D_1 and D_2 conduct.

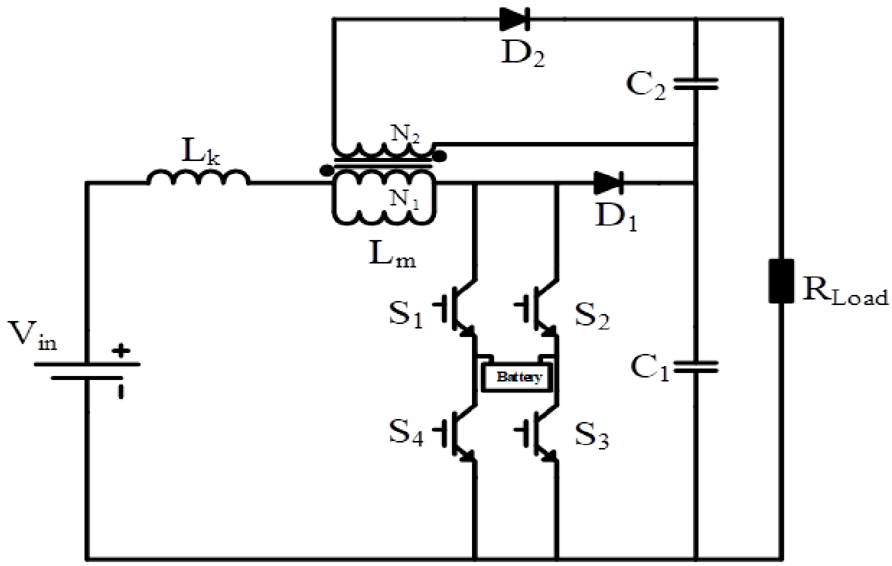

Figure 1: Circuit structure of the proposed converter.

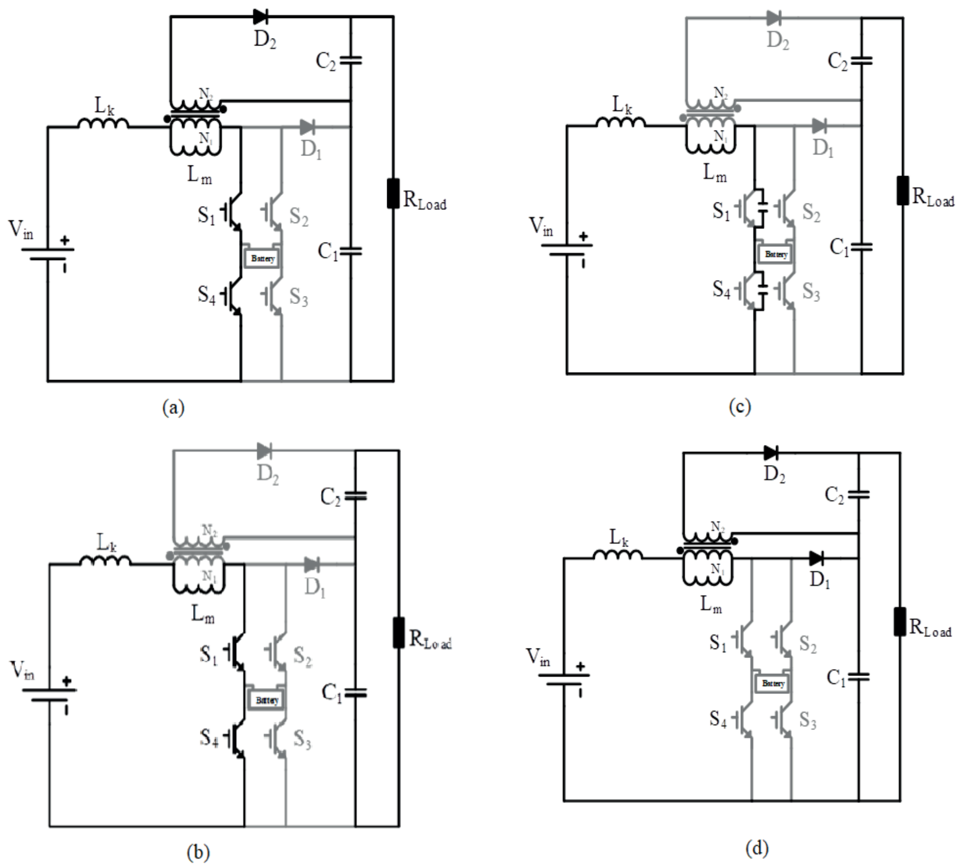

Figure 2: Sub-modes of the proposed converter in mode-I: (a) [t_0-t_1], (b) [t_1-t_2], (c) [t_2-t_3], (d) [t_3-t_4]

Fourth Sub-Mode [t_3 – t_4]: In this sub-mode, each of the leakage and magnetizing inductors face different parallel voltages. The difference between the inductors' current is transferred to the secondary side of the coupled inductor to charge capacitor C_2. Capacitor C_1 charges with leakage inductors' current and this sub-mode lasts until the power switches turn on.

Fig. 3 shows some of the waveforms of the proposed converter in mode one. The waveforms include power switches turning on and off times, input current, magnetizing inductor current and diodes current. To calculate the output voltage's gain of the proposed converter, the following condition is assumed:

1. The proposed converter operates in continuous conduction mode (CCM);
2. Due to the small size of the leakage inductor, it is not considered in calculations.

Eq. (1) is a general assumption in proposed converter calculations.

$$V_o = V_{C1} + V_{C2} \tag{1}$$

where V_O, V_{C1}, and V_{C2} are output voltage, first capacitor's voltage and second capacitor's voltage, respectively.

In mode one, consideration is not given to sub-mode one and sub-mode three in calculations due to their small and unimportant size. In DT interval, D is equal to duty cycle, and T stands for the period of the switching, giving:

$$V_{Lm} = V_{in} \tag{2}$$

where V_{Lm} and V_{in} are magnetizing inductor's voltage and input voltage, respectively.

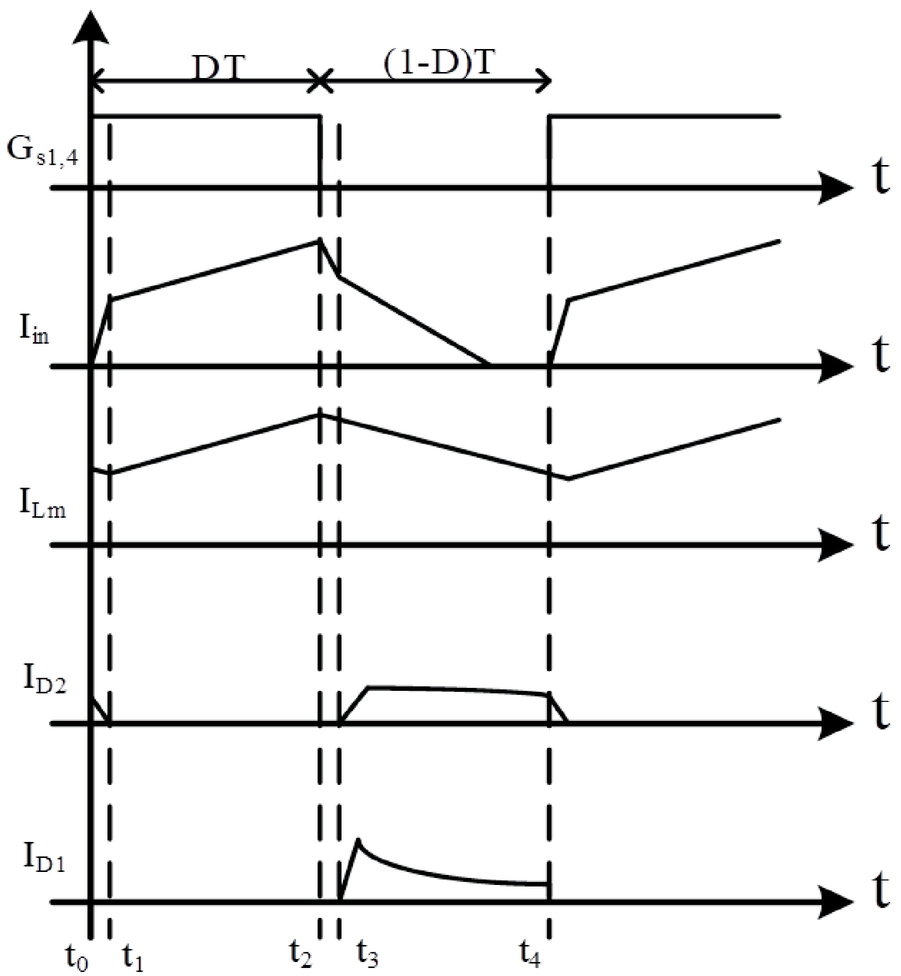

Figure 3: The proposed converter's equivalent waveforms in mode-I

$$V_{Lm} = V_{in} - V_{C1} \tag{3}$$

$$V_{Lm} = -\frac{N_1}{N_2} V_{C2} \tag{4}$$

Using (2), (3) and (4), the following relationship can be obtained:

$$V_{C1} = \frac{V_{in}}{1-D} \tag{5}$$

$$V_{C2} = \frac{\frac{N_2}{N1} D V_{in}}{1-D} \tag{6}$$

In the end, by using (1), (5) and (6) output voltage gain is:

$$V_o/V_{IN} = (1 + (N_2/N_1)D)/(1 - D) \tag{7}$$

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continues from page 21

BATTERY CHARGING (MODE II)

In this mode, extra produced energy is stored in the battery. Sub-modes of the converter in this mode is illustrated in Fig. 4. Waveforms of the converter in this mode are depicted in Fig. 5.

First Sub-Mode [t_0 – t_1]: This mode starts by turning on switches S_1, S_4 or S_2, S_3. Just same as first sub-mode of Mode one, due to difference in leakage and magnetizing inductors current value, diode D_2 conducts. Leakage and magnetizing inductors current difference charges capacitor C_2 on the secondary side of the coupled inductor.

Second Sub-Mode [t_1 – t_2]: This sub-mode is the same as the respective sub-mode of mode one, and it starts when leakage and magnetizing inductors' stored energy become equal with each other and diode D_2 turns off. This sub-mode lasts until the power switches turn off.

Third Sub-Mode [t_2 – t_3]: By turning switch S_4 off and turning switch S_3 on, this sub-mode starts. In this sub-mode, the power source energy transfers to the battery and leakage and magnetizing inductors charge with lower slope (assuming the power source voltage is higher than the battery voltage).

Fourth Sub-Mode [t_3 – t_4]: By starting this sub-mode, the power switches turn off. In this sub-mode, the switches' parallel capacitors start to charge by turning the power switches off. The capacitors continue charging until the switches' parallel capacitors' voltage reach that of capacitor C_1's. In this mode, inductors' stored energy decreases and this mode finishes when diode D_1 and D_2 conduct.

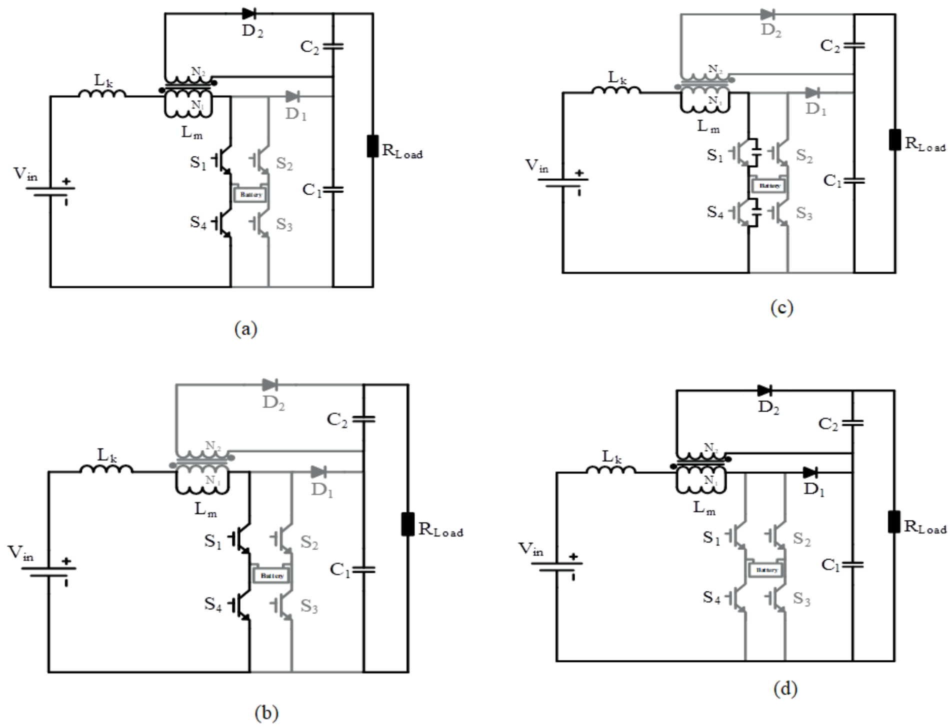

Figure 4: Sub-modes of the proposed converter in mode-II: (a) [t_0-t_1], (b) [t_1-t_2], (c) [t_2-t_3], (d) [t_3-t_4] , (e) [t_4-t_5]

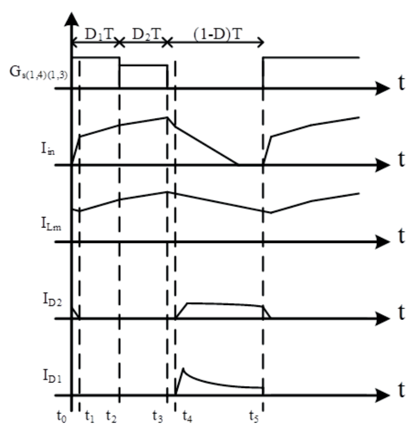

Figure 5: The proposed converter's equivalent waveforms in mode- II

Fifth Sub-Mode [t_4 – t_5]: As in the previous mode, in this sub-mode, each of the leakage and magnetizing inductors face different parallel voltages. The difference of the inductors' current transfers to the secondary side of the coupled inductor to charge capacitor C_2. Capacitor C_1 charges with leakage inductors' current and this sub-mode last until the power switches turn on.

The waveforms of the proposed converter in mode two are depicted in Fig. 5. D_1 and D_2 are the equivalent duty cycle of the proposed converter for charging the inductors without battery and with battery, respectively. In Fig. 5, Iin stands for input current, I_{Lm} stands for current flowing through the magnetizing inductor, and ID_1 and ID_2 stand for current flowing through diodes.

To calculate the output voltage's gain in this mode, assumptions of Mode-I are valid.

For interval D_1+D_2, we have:

$$V_{Lm} = (D_1 + D_2)V_{in} - D_2V_{Battery} \quad (8)$$

And for interval 1-(D1+D2), we have:

$$V_{Lm} = V_{in} - V_{C1} \quad (9)$$

$$V_{Lm} = -\frac{N_1}{N2}V_{C2} \quad (10)$$

Using (8), (9) and (10) results in:

$$V_{C1} = \frac{V_{in} - D_2V_{Battery}}{1 - D_1 - D_2} \quad (11)$$

$$V_{C2} = \frac{\frac{N_2}{N1}}{1 - D_1 - D_2}\left[V_{in}(D_1 + D_2) - D_2V_{Battery}\right] \quad (12)$$

Finally, by using (1), (11) and (12) output voltages gain in mode two is calculated as:

$$V_O = \frac{V_{in}\left[1 + \frac{N_2}{N1}(D_1 + D_2)\right] - V_{Battery}D_2\left[\frac{N_2}{N1} + 1\right]}{1 - D_1 - D_2} \quad (13)$$

BATTERY DISCHARGING (MODE-III)

In this mode, the power source is assumed to be unable to provide the load's required energy and the battery is responsible for supplying the rest of the necessary energy.

For instance, the supply shortage may include PV during the night time or very high and very low wind velocities for wind turbines, etc. Waveforms of the proposed converter are depicted in Fig. 6.

First Sub-Mode [t_0 – t_1]: This mode starts by turning on switches S_1, S_4 or S_2, S_3. Just same as first sub-mode of Mode one and Mode two, due to difference in leakage and magnetizing inductors current value, diode D_2 conducts. Leakage and magnetizing inductors' current difference charges capacitor C_2 at the secondary side of the coupled inductor. Magnetizing inductors current decrease due to negative voltage on it; however, leakage inductors stored energy increase.

Second Sub-Mode [t_1 – t_2]: This sub-mode starts when leakage and magnetizing inductors' stored energy become equal with each other and diode D_2 is turned off as in mode one and mode two. This sub-mode lasts until the power switches turn off.

Third Sub-Mode [t_2 – t_3]: By turning off switch S_1 and turning on switch S_2 this sub-mode starts. In this sub-mode, the power source and battery charge and leakage and magnetizing inductors with a higher slope.

Fourth Sub-Mode [t_3 – t_4]: This sub-mode starts when the power switches turn off. Switches' parallel capacitors start to charge by turning the power switches off. The capacitors continue charging until the switches' parallel capacitors' voltage reach that of capacitor C_1's. In this mode, the inductors' stored energy decreases and this mode finishes when diode D_1 and D_2 conduct.

Fifth Sub-Mode [t_4 – t_5]: As in previous modes, in this sub-mode, each of the leakage and magnetizing inductors face different parallel voltages. The difference of the inductors' current transfers to the secondary side of the coupled inductor to charge capacitor C_2. Capacitor C_1 charges with leakage inductors' current and this sub-mode last until the power switches turn on.

Fig. 7 shows waveforms of the converter in mode three. D_1 and D_2 are inductors' charging duty cycle without battery and with battery discharging, respectively.

For D_1+D_2 interval, we have:

$$V_{Lm} = (D_1 + D_2)\,V_{in} + D_2V_{Battery} \quad (14)$$

Also, for 1- D_1-D_2 interval we have:

$$V_{Lm} = V_{in} - V_{C1} \quad (15)$$

$$V_{Lm} = -\frac{N_1}{N2}V_{C2} \quad (16)$$

The following relationship can be gained by using (14), (15) and (16):

$$V_{C1} = \frac{V_{in} + D_2V_{Battery}}{1 - D_1 - D_2} \quad (17)$$

$$V_{C2} = \frac{\frac{N_2}{N1}}{1 - D_1 - D_2}\left[V_{in}(D_1 + D_2) + D_2V_{Battery}\right] \quad (18)$$

The output voltage gain of the proposed converter in Mode-III can be calculated using (1), (17) and (18) as follows:

$$V_O = \frac{V_{in}\left[1 + \frac{N_2}{N1}(D_1 + D_2)\right] + V_{Battery}D_2\left[\frac{N_2}{N1} + 1\right]}{1 - D_1 - D_2} \quad (19)$$

EXPERIMENTAL RESULTS

By verifying the performance of the proposed converter, an innovative circuit is investigated. The performance of the converter in exploratory research is divided into three modes, reflecting the performance principles. The switching frequency of the proposed converter in this research is about 30 kHz, and the voltages of the input and battery are 20 V and 15 V, respectively. The load is about 100 V for all of the experimental tests, and we tested the proposed converter on its capability to provide all three modes. Fig 8 shows the performance of the converter in the first mode (Without Battery). From up to down waveforms are output voltage, input current, diode D_2's current and diode

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D_1's current. According to equation (7), out voltage of the proposed converter in this mode considering $D = 1/3$ should be 140 V which the experimental results verify. Input current is about 12 A in its peak and waveform is similar to expected outcomes in Fig. 3. Diode D_1, 2s' currents are identical to presumed waveforms in Fig. 3 and are about 5 A and 10 A at their peak respectively.

Experimental results for the second mode (Battery Charging) is depicted in Fig. 9. In this mode, $D_1 = 1/3$ and $D_2 = 1/3$, which results in 95 V according to (13). Experimental results in Fig. 9 verify the performance of the converter in this mode. In Fig. 9 waveforms are ordered similar to the first mode (Fig. 8). As was expected, input current, diode D_2 current and diode D_1 current are identical to waveforms in Fig. 5. Input's, diode D_2's and diode D_1's currents at their peaks are 8 A, 4 A and 6 A, respectively.

Fig. 10 shows experimental results for the third mode (Battery Discharging). In this mode, waveforms are ordered similarly to the previous results. The proposed converter operates with $D_1 = 1/3$ and $D_2 = 1/3$ in this mode. Equation (19) shows that the output voltage in this mode is 185 V, which experimental results verify. In this mode input's, diode D_2's and diode D_1's currents are 18 A, 8 A and 12 A at their peaks respectively. Waveforms are similar to Fig. 7 as was expected.

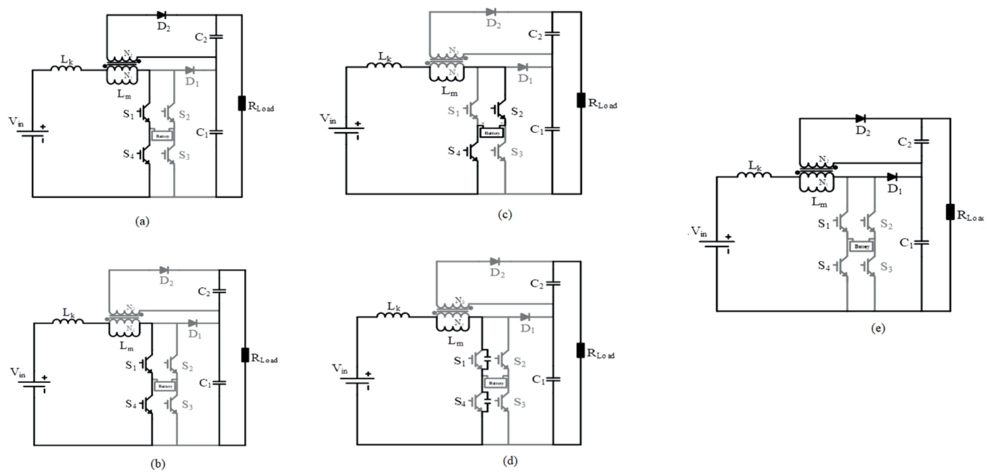

Figure 6: Sub-modes of the proposed converter in mode-III: (a) $[t_0\text{-}t_1]$, (b) $[t_1\text{-}t_2]$, (c) $[t_2\text{-}t_3]$, (d) $[t_3\text{-}t_4]$, (e) $[t_4\text{-}t_5]$

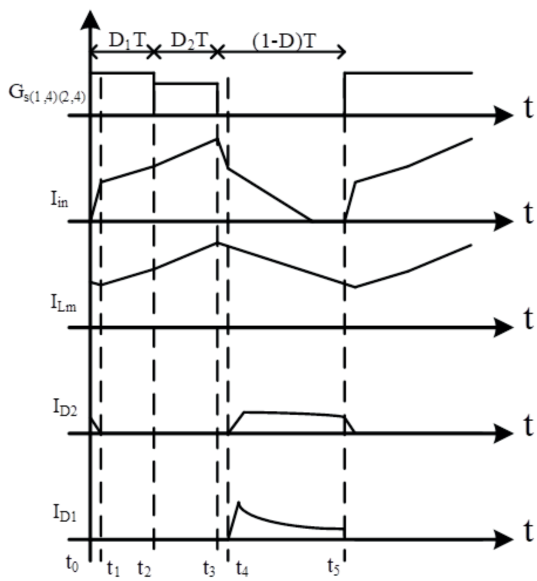

Figure 7: The proposed converter's equivalent waveforms in mode- III .

CONCLUSION

In this paper, a newly developed high step-up double input DC-DC converter was presented. The performance of the proposed converter was evaluated in three different modes (namely, without battery, with battery charging, and with battery discharging). Also, operation of the presented structure in each of the Modes was described, and equivalent equations were calculated. By verifying the theoretical performance of the converter, the experimental results were also provided. The results are very consistent both in theory and experiment. wn

REFERENCES:

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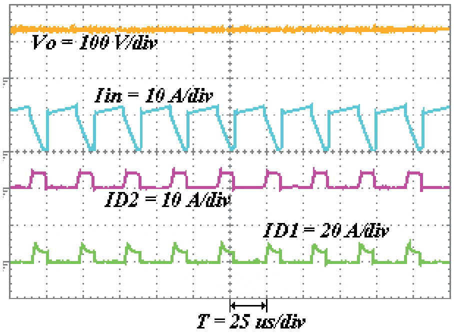


Figure 8: Experimental results for the proposed converter in mode-I.

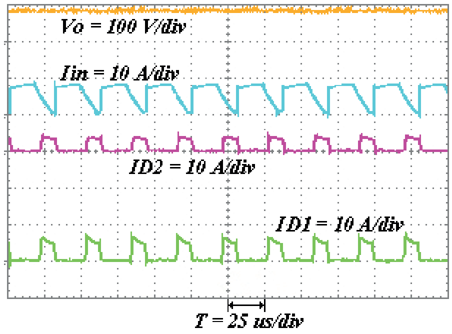


Figure 9: Experimental results for the proposed converter in mode-II .

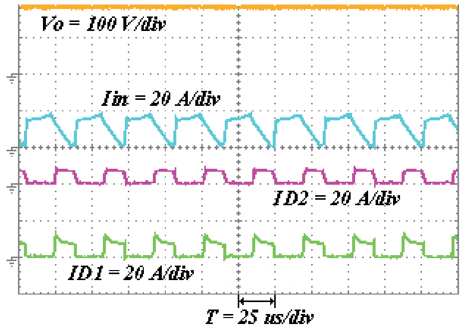


Figure 10: Experimental results for proposed converter in mode-III.

The Speed of the Energy Transition...

- Gradual or Rapid Change?

Will the global energy transition from fossil fuels to sustainable energy be gradual or rapid? This vital issue for the 2020s has profound implications for governments, energy producers, technology providers as well as industrial and private consumers. But, more importantly, the difference between a gradual and rapid transition will determine the climate future of humanity.

BY | CHRISTINA LAMPE-ONNERUD, CO-CHAIR OF THE GLOBAL FUTURE COUNCIL ON ENERGY

JULES KORTENHORST
CO-CHAIR OF THE GLOBAL FUTURE COUNCIL ON ENERGY

A gradual transition will mean that the goals of the Paris Agreement will be badly missed. A quick change will give humanity a chance to meet the purposes of the Paris Agreement and keep the temperature well below 2 degrees Celsius.

Intending to both inform and spark further debate, this White Paper compares the two transition scenarios for our energy future, setting out two different narratives.

The Gradual narrative is that the energy world of tomorrow will look roughly the same as that of today – implying that the global energy system has inertia incompatible with the Paris Agreement.

The Rapid narrative is that current and new clean energy technologies are rapidly supplying all the growth in energy demand. Together with new policies, it will then reshape markets, business models and patterns of consumption leading to a peak in fossil fuel demand in the course of the 2020s.

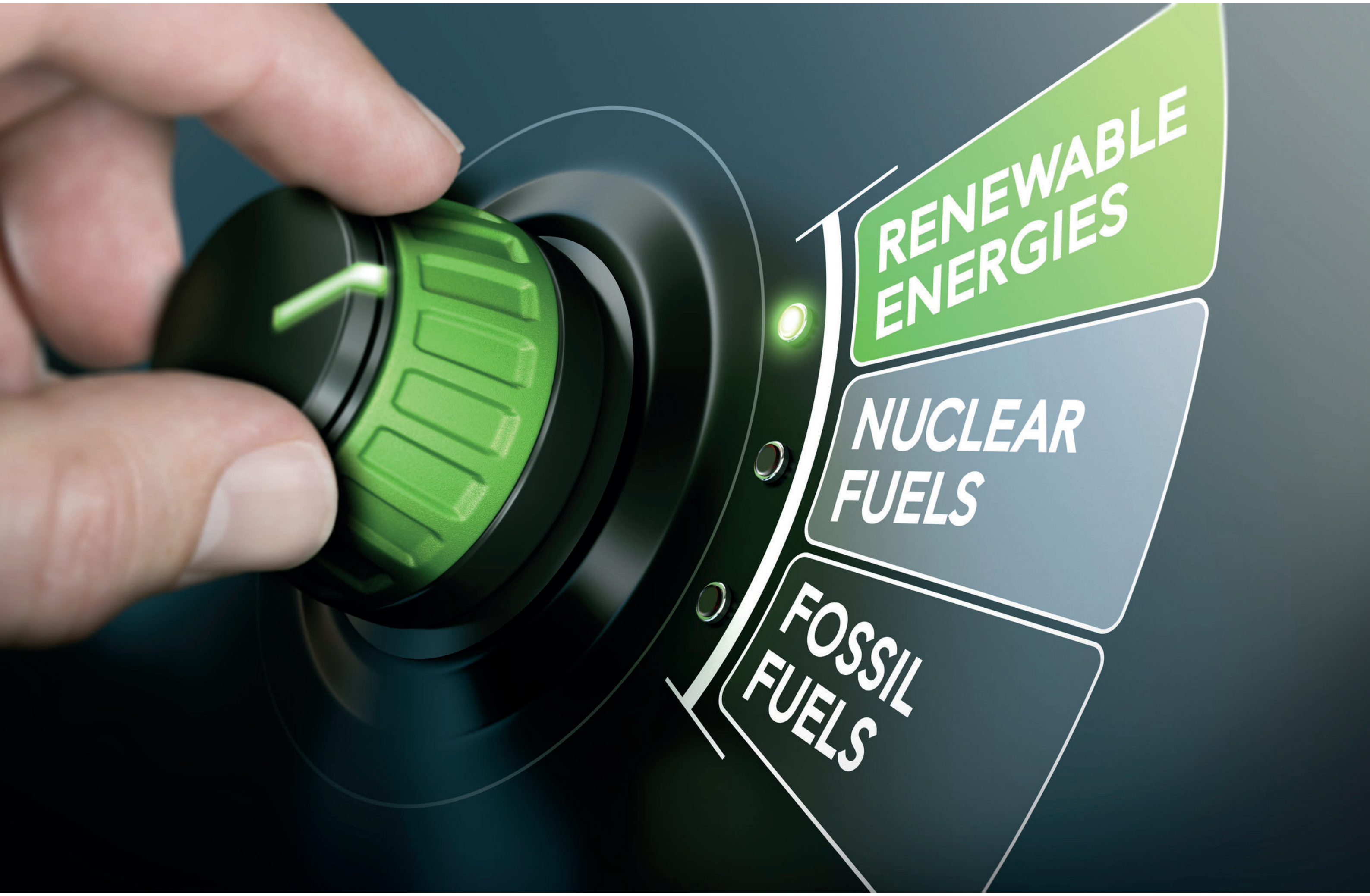
Whether the world will follow a path of a gradual or rapid transition will also make a significant difference to business across the energy spectrum. The rapid transition will bring new opportunities, but they need to adapt to faster change will be higher.

While the global energy system and the factors that impact it are more complex than any scenario or narrative can capture, this paper builds on different existing situations. It summarises the main ways in which they differ. It also highlights what to look for over the next decade to see which narrative plays out.

The Global Future Council on Energy 2018-2020 strives to inform the debate and decisions for the near- and long-term energy future.

While acknowledging lead authors Kingsmill Bond, New Energy Strategist, Carbon Tracker Initiative; Angus McCrone, Chief Editor, BloombergNEF; and Jules Kortenhorst, Chief Executive Officer, Rocky Mountain Institute, this White Paper includes significant input and insights from our Council (see the list of members at the end of the paper).

The findings, interpretations and conclusions expressed herein are the results of a collaborative process facilitated by the World Economic Forum. Still, they do not necessarily represent the views of the Forum, nor the entirety of its Members, Partners or other stakeholders, nor the individual Global Future Council members listed as contributors, or their organisations.



EXECUTIVE SUMMARY

The great energy debate. The energy industry is complex, and understanding the major trends changing the industry can be challenging. Investors, policy-makers, business people and other interested stakeholders require precise information about the evolution of the energy system to inform present decisions, which can have long-lasting effects. This White Paper provides a framework for navigating the mosaic of often conflicting narratives for how the energy system is evolving. The two very different narratives about the energy transition are Gradual and Rapid. This paper summarises the ways they differ and what to look for over the next decade to see which narrative is playing out.

The Gradual narrative is that the energy world of tomorrow will look roughly the same as that of today. Gradual scenarios extrapolate current patterns of policy, industry, consumption and investment, thus supporting planned carbon-intensive investment decisions and implying that the global energy system has inertia incompatible with the Paris Agreement.

The Rapid narrative is that new energy technologies are rapidly supplying all the growth in energy demand, leading to peak fossil fuel demand in the course of the 2020s. Rapid scenarios suggest that current technologies and new policies will reshape markets, business models and patterns of consumption, challenging planned carbon-intensive investment and leading to a low-carbon global economy while creating considerable economic and social benefits.

The narrative can become self-fulfilling. Energy systems have considerable inertia. If investors and policy-makers believe that future energy demand and supply structures will be broadly the same as today, they will invest accordingly, helping to lock in the current system. If they believe that change is likely, they will invest in and legislate for new opportunities, speeding up the transition.

The road to Paris. Gradual scenarios recognise with regret that carbon emissions will continue to rise, making compliance with the Paris Agreement ever more challenging to achieve. Rapid situations provide a framework under which global emissions can reach the goals of the Paris Agreement.

Implications for the fossil fuel sectors. Gradual scenarios imply that peak fossil fuel demand is at least a generation away. Growing economies and populations will drive continued growth in demand for

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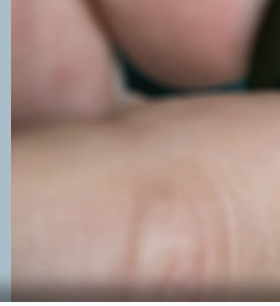

natural gas, oil and, to a lesser extent, coal and that the impact of the transition on these sectors will be muted with a gradual shift towards natural gas within the fossil fuel mix. Rapid scenarios imply that the demand for fossil fuels will peak in the 2020s and the same technology, policy, consumer and financial pressures that are being felt across the energy system at present will affect all fossil fuel sectors. And as technology improves, the fungibility between fossil fuels and renewables will further increase. The implications for the world's fossil fuel sectors are significant: either they will thrive for years to come, or they are about to be disrupted and need radical change.

What determines the difference. Four main features distinguish the two narratives: what matters, technology growth, policy and emerging market energy pathways. Views on these issues largely determine conclusions on where the energy markets are heading.

1. What matters – stock or flow. Gradual advocates and scenarios focus on total demand (stock) and argue that new energy technologies are relatively small and will take decades to overtake fossil fuels. Rapid advocates focus on change (flow) and say that new energy technologies will soon make up all the growth in energy supply.
2. Technology growth – linear or exponential. Gradual advocates argue that new energy technologies are expensive and face insoluble economic or technical impediments to increase, meaning that growth rates will only be linear. Rapid advocates say that solar and wind are already cheaper than fossil fuels for the generation of electricity. Electric vehicles (EVs) are about to challenge internal combustion engines (ICEs) on price, that the barriers to growth are soluble for the foreseeable future, and that these disruptive new energy technologies will continue to enjoy exponential growth. They anticipate the rise of new technologies, such as green hydrogen, to lead to further waves of change.
3. Policy – static or dynamic. Gradual advocates argue that it is necessary only to model policies that are certain to happen, that the forces of inertia are mighty and that policy-makers will remain cautious and slow-moving. Rapid advocates argue that the effects for change are considerably higher than those for inactivity and that technology opens up the opportunity for policy-makers and regulators to design markets to better provide for all consumers' needs. As the necessity for action becomes clear, there will be an Inevitable Policy Response.1 Modelling only the existing policy environment understates trends in policy-making.
4. Emerging market energy pathways – copy or leapfrog. Gradual advocates argue that the emerging markets (including China and India) will broadly follow the path taken by developed markets and use more fossil fuels as they get more productive and energy demand rises. Recent years' investments in infrastructure, such as coal-fired plants, are seen to lock in consumption for years to come and increase the costs of transition, thereby slowing down its pace. Rapid advocates argue that the emerging markets will enjoy an energy leapfrog to new energy technologies and significantly less energy-intensive forms of economic development while providing critical improvements in the quality of life.

Is the energy transition just about solar and wind? Gradual advocates argue that solar and wind are too small to drive an energy transition. Rapid advocates argue that technology disruption started with solar and wind, has since spread to renewable integration technologies, is now moving into transport, and will shift into other areas of energy. As in any transition, the low-hanging fruit of change is plucked first, leaving the more problematic areas for later.

How important are different fossil fuels? Gradual advocates note that coal, oil and natural gas and every fossil fuel sector in every country are different, and highlight the areas that appear to have few renewable energy alternatives.

Rapid advocates argue that the energy transition will drive peaks in one fossil fuel sector after another. First coal, then oil, then gas will be impacted, in one country after another, in a pattern whose shape and trajectory will become increasingly familiar.

What is the role of finance in the energy transition? Gradual advocates argue that the capital invested in the fossil fuel sectors, and the market need for fossil fuels, are so considerable that investors in aggregate will not speed up the transition. They will instead be a neutral force investing across the energy spectrum where they see the best opportunities for returns on capital. Rapid advocates argue that the financial sector as a whole will act to increase the speed of change as it searches for new growth opportunities, becomes more environmentally sustainable and restricts the flows of capital to declining industries.

What about countries that resist the energy transition? Gradual advocates note that many fossil fuel exporters and the current US administration are resistant to an energy transition, and large emerging economies like China and India will continue to fuel demand growth for all energy sources. Rapid advocates note that four out of five people live in countries that import fossil fuels, meaning that they would stand to benefit from a transition to local renewable energy sources. In particular, China and India are the largest and third-largest fossil fuel importers and are strongly committed to a change.

Can technology solve everything? While technology is increasingly devising cost-effective solutions that will drive an energy transition, the forces of inertia are mighty. Therefore, policy-makers will need to play an active role in the goals of the Paris Agreement to be achieved in time.

Don't shoot the messenger. In an increasingly fraught world, it is essential to note that some organisations whose data is referred to in this paper are providers of scenarios, not necessarily advocates of one narrative or the other.

Recent developments. Gradual advocates point to a rapidly rising energy demand, the roll-back of environmental protection in the US and the fact that renewable energy capacity growth in 2018 was similar to that in 2017. Rapid advocates point to the continued and unexpected fall in renewable costs, the continued S curves of new energy technology growth, and the rising pressure from financial markets and society for policy-makers to take more aggressive action. They note that disruption is already happening in a series of energy and related sectors, from coal to electricity, turbines to cars.

What to watch out for. The key issues to watch over the next decade have been laid out to see which narrative will prevail. In technology, the focus is on the cost and growth rates of the key disruptive technologies – solar, wind, batteries, EVs and green hydrogen. In policy, the focus is on whether politicians implement more rigorous actions to make fossil fuel users pay for their greenhouse gas externalities. In the emerging markets, the question is whether China and India will be able to continue to implement new clean energy and energy efficiency technologies at scale and whether South-East Asia and Africa will follow the path they are setting.

Signposts. A series of signposts are presented. Pass these, and the Rapid narrative is on track. Fail to pass them, and the Gradual narrative is playing out. Three targets have been set for 2030: solar electricity at $20-30 per megawatt hour (MWh); advanced lithium-ion batteries at $50-100 per kilowatt hour (kWh); and carbon taxes implemented on around half of emissions at $20 per tonne, with three peaks to take place in the 2020s in the event of Rapid transition: peak demand for new ICE cars; peak demand for fossil fuels in electricity; and peak demand for all fossil fuels.

ENERGY TRANSITION NARRATIVES

There are as many scenarios for the future of energy as there are forecasters, and it is of course not possible to know in advance which one is optimal. Paul Warde, the Cambridge energy historian, notes[2] that most long-term energy projections have been consistently wrong,[3] that projections have tended to have a significant bias in favour of the person asking the question, and that most forecasts have overestimated future demand.

Nevertheless, scenarios can be grouped into two primary narratives about the speed of the energy transition:[4] a gradual transition (Gradual); and a rapid transition (Rapid). In discussions about the future of energy, advocates of both sides will tend to select those scenarios and models that fit with their narrative. It is important to note that some organizations do not publish forecasts but scenarios; these scenarios can be used by advocates on both sides of the debate.

It is the narrative that sets expectations for the future, and this in itself is important because it determines how governments, companies and individuals allocate their resources.[5]

Gradual

Gradual scenarios include those from Exxon,[6] the Organization of the Petroleum Exporting Countries (OPEC),[7] the World Energy Council[8] and the Energy Information Administration,[9] as well as the IEA New Policies Scenario (NPS),[10] and the BP Evolving Transition Scenario (ETS).[11]

These scenarios imply that the energy world of tomorrow will look roughly the same as that of today. Fossil fuel demand will rise for the foreseeable future and, when it does start to decline, the decline will be gradual.

Regrettably, this means that the goals of the Paris Agreement will become increasingly unachievable. Figure 1 shows an example from BP's ETS.

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Figure 1: Energy supply (EJ), Gradual narrative, 2015-2040

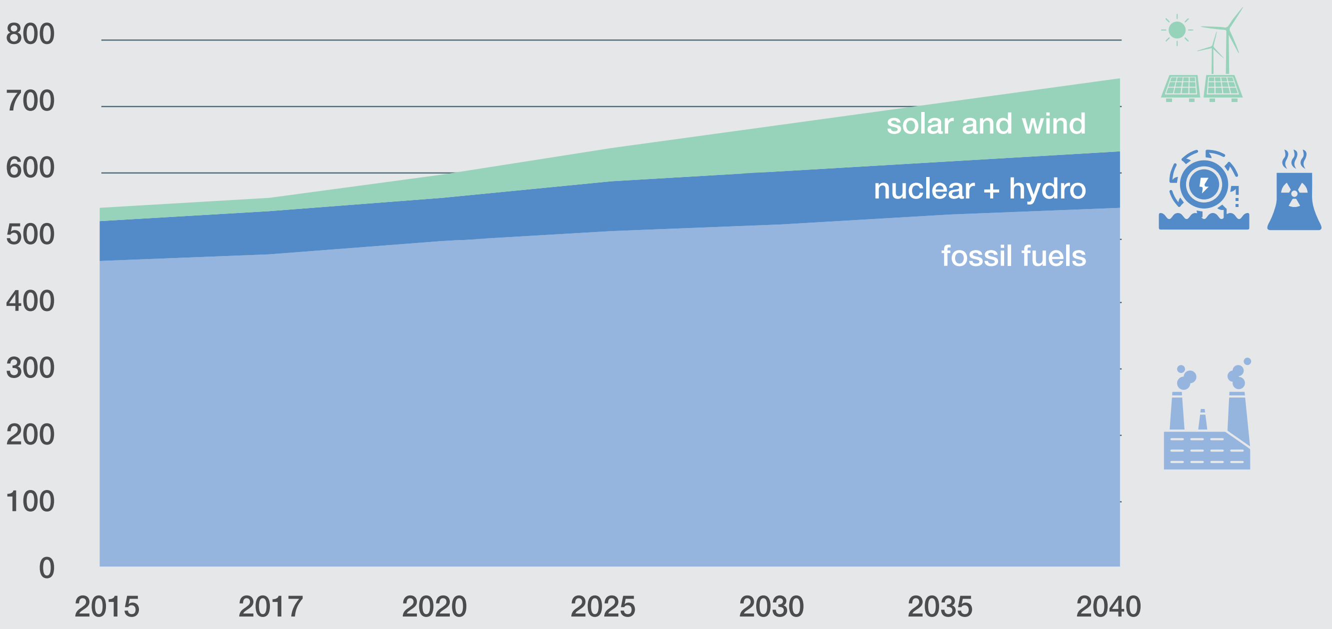
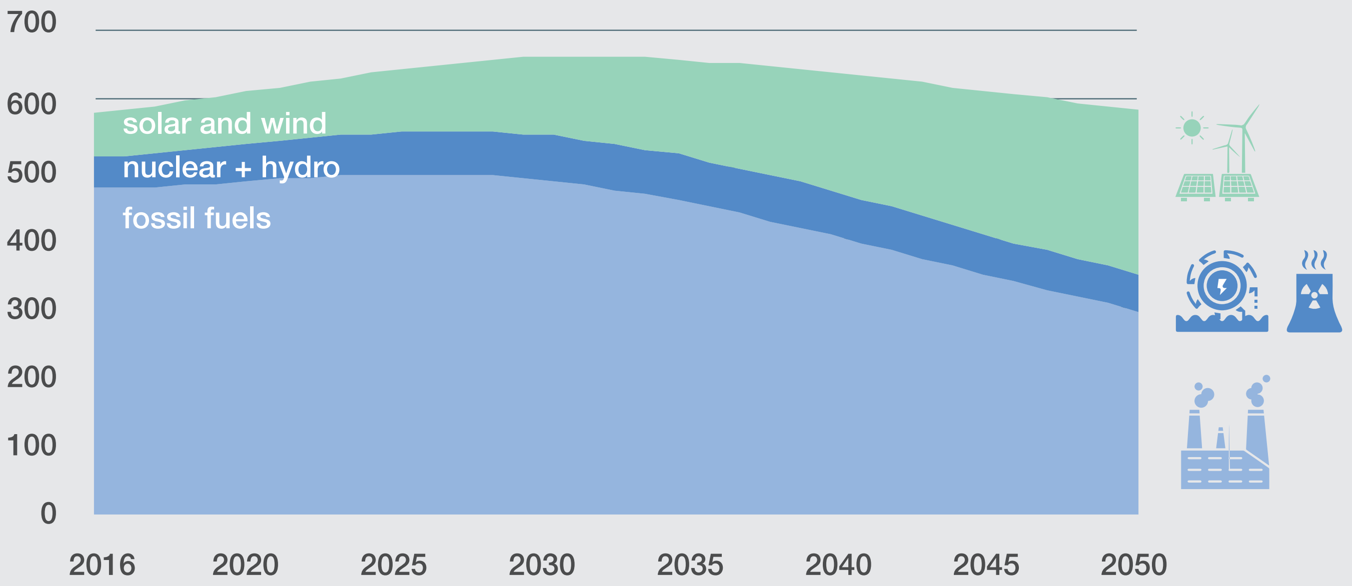


Figure 2: Energy supply (EJ), Rapid narrative, 2016-2050



Rapid

Rapid scenarios include normative scenarios,[12] such as the IEA Sustainable Development Scenario (SDS),[13] the International Renewable Energy Agency (IRENA) REMap,[14] the Intergovernmental Panel on Climate Change (IPCC) less than two-degree models,[15] the BP Rapid Transition Scenario,[16] the International Institute for Applied Systems Analysis (IIASA) Low Energy Demand Scenario[17] and the Shell Sky Scenario,[18] as well as the primary scenarios of organizations such as Bloomberg New Energy Finance (BloombergNEF),[19] DNV GL,[20] McKinsey[21] and the Energy Transitions Commission.[22]

As a rule, these scenarios seek to achieve the goals of the Paris Agreement,[23] and imply that the energy sector is about to be disrupted. They forecast rapid growth in solar and wind electricity, the gradual electrification of transport, industry and heat, higher efficiency, policy action to tax fossil fuel users for their environmental externalities, and the development of new technologies like green hydrogen.

They imply that demand for fossil fuels will soon peak and then enter a long period of decline. Figure 2 shows an example of the DNV GL energy forecast.

It is important to emphasize that the Rapid path is the more difficult of the two. It will require a significant coordinated effort of policy, technology development and behaviour from all sections of society to drive change across the whole of the economy on the timescale needed to achieve the goals of the Paris Agreement.

DIFFERENCES BETWEEN THE TWO NARRATIVES

The differences between the two narratives can be summarised concerning four key features: what matters, technology growth, policy and emerging market energy pathways. Of course, many other important drivers of the energy transition exist, such as efficiency or digitization. Still, these tend to be a feature of both narratives and are not the focus of this paper.

The energy sector is highly complex, and a large number of variables in any scenario makes them hard to compare; as a result, examples seek to illustrate rather than to be comprehensive in this analysis. Not all scenarios fit neatly into the divisions describe below, and each needs to be judged on its own merits. Moreover, some situations will, of course, be more extreme than others. Nevertheless, the chasm between the two narratives is sufficiently wide to merit some analysis.

What Matters

At the start of this review, the assumption was that it would be possible to have a common starting point based on the facts for 2018. However, the facts can be interpreted very differently, depending on the narrative. The focus is on four main points of difference: what matters for the energy transition; the importance of electricity; the importance of solar and wind; and the importance of distinguishing between fossil fuels.

Total Supply or Change in Supply?

What is the issue?

Should analysts focus on total supply or change in supply? For example, the total supply of a product may be 100 units, projected to fall to 90 units in a decade. The analyst looking at total supply will argue that supply is still high, at 90 units. The analyst looking at change will say that supply has peaked and fallen by ten units.

Total energy supply growth is usually 1-2% per annum, so the difference between aggregate supply and the change in supply is significant – nearly two orders of magnitude. In 2017, for example, the total primary energy supply was 13,475 million tonnes of oil equivalent (Mtoe), and the change in supply was 246 Mtoe, according to BP.[24]

Gradual approach

The Gradual approach focuses on total supply and notes that, even with relatively high renewable growth, total supply for fossil fuels will remain high with a gradual shift towards natural gas within the mix of fossil fuels as a cleaner option to coal.[25] The energy historian Vaclav Smil comments that it will take many decades for renewable energy to overtake fossil fuels in terms of market share, and he argues that the move away from fossil fuels will be a protracted affair.[26] In Figure 3 from BP showing total energy supply over the last decade, it is tough to see any impact from solar and wind, for example.

Rapid approach

The Rapid approach does not deny that fossil fuels will continue to play a significant role in energy markets for decades to come. The difference lies in the fact that the Rapid approach focuses on the change in supply and notes that the effects of evolution are felt by companies in these sectors as growth in their core markets turns to decline,[27] and are priced by financial markets even before supply peaks. Moreover, once a tipping point is reached, financial markets

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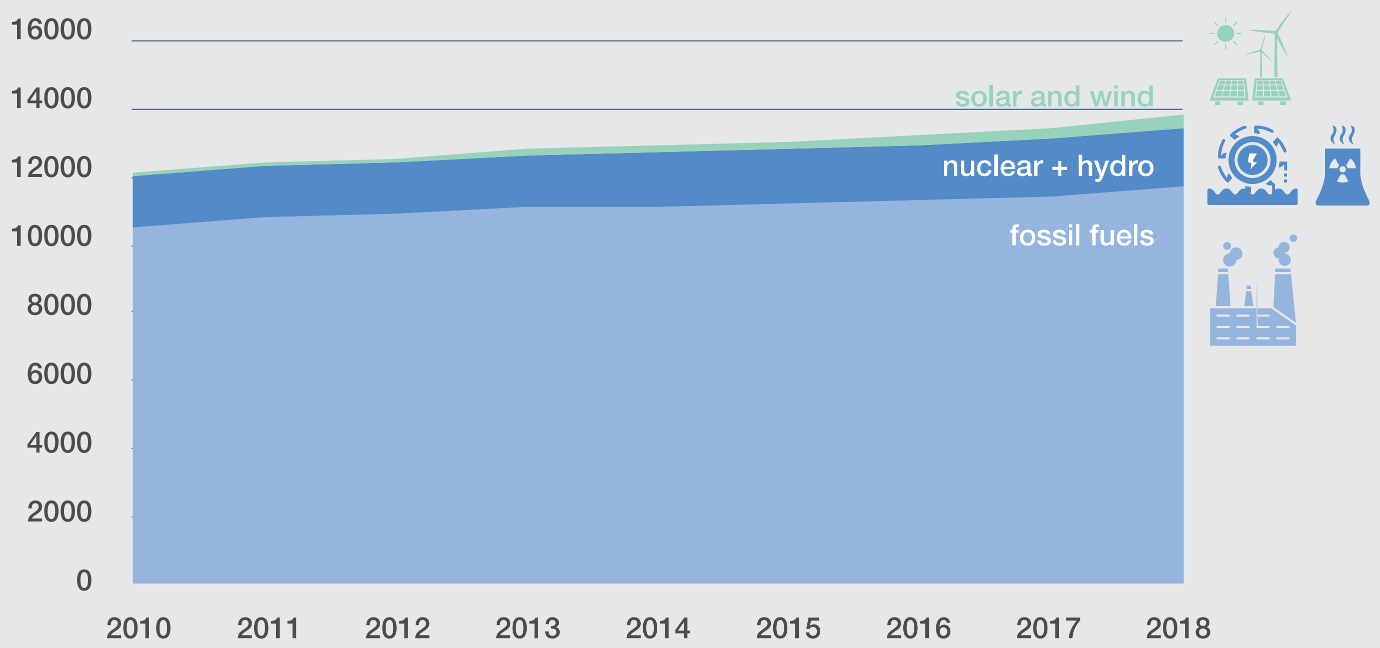
Figure 3: Total energy supply (Mtoe), 2010-2018



will tend to speed up the pace of change by constraining capital to declining industries and reallocating it to those that are growing.

The four most well-known examples of this process in recent years are electricity in Europe, coal, fossil fuel turbines and the car sector. In each case, incumbents were disrupted, and stock prices impacted at around the time that demand for their product peaked. Advocates, therefore, focus on how long it will take for new energy technologies to supply all the growth.

If total supply growth is 246 Mtoe and non-fossil supply growth is 90 Mtoe, there will be many countries and sectors where fossil fuel supply has already peaked and is falling.

To take three examples from the BP statistical review: European oil demand peaked in 2007 and has since fallen by 14%; Chinese coal demand peaked in 2013 and has fallen by 3%, and Japanese gas demand peaked in 2013 and is since down by 6%.

Taking the same data as that set out above, but for the change in energy supply, a very different picture emerges (Figure 4). Non-fossil sources made up nearly one-third of the growth in energy supply in 2018, and the amount of energy they produce continues to snowball. Energy demand growth in 2018 was unusually high; if it had been the same level as in 2015, for example, then non-fossil sources would already be supplying all the growth in energy demand.

How Important is Electricity?

What is the issue?

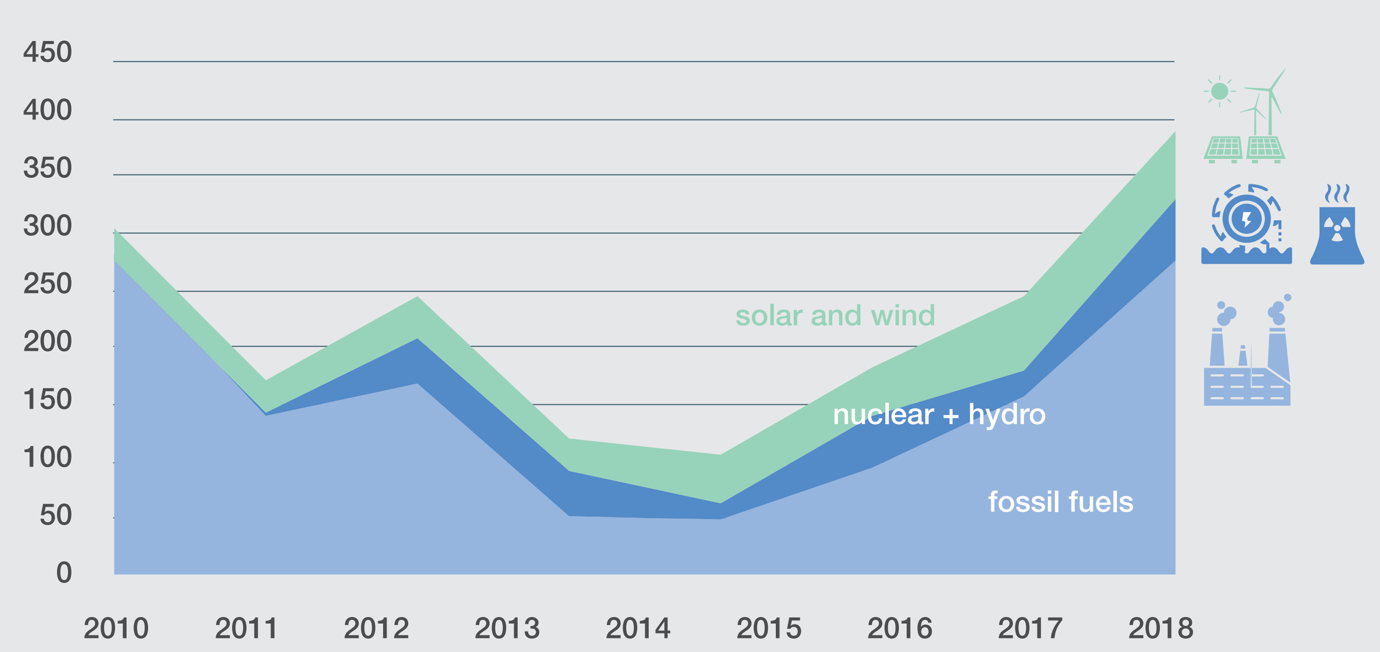
Final energy consumption includes both electricity (a high-quality energy carrier) and other energy sources, such as coal, oil and gas. However, electricity can be used with minimal losses for energy services (like turning on a light). At the same time, fossil fuels lose about two-thirds of their energy in thermodynamic losses when they are converted into most forms of useful energy. The question then is how to compare the two.[28]

In 2017, electricity was 19% of total final energy consumption and 38% of total primary energy demand, according to the IEA.[29] Because of the continued electrification of a range of sectors, electricity was 56% of the increase in total primary energy demand. The question is: which of these numbers is more relevant?

Gradual approach

The Gradual approach compares electricity with fossil fuels as if they were equivalent and notes that a profound restructuring of the entire energy system is needed. Advocates argue that electricity is a small share of total final consumption, so growth

Figure 4: Change in energy supply (Mtoe), 2010-2018



in that area is likely to be offset by continued fossil demand growth in other areas.

Rapid approach

The Rapid approach seeks to adjust for the thermodynamic losses of fossil fuels by looking at total primary energy demand. From that perspective, electricity used 38% of all primary energy in 2017. They looked at the change in demand, where electricity was 56% in 2017 and is likely to increase to two-thirds as a result of rising electrification of end-use sectors, such as transport and heat.

Electricity, therefore, assumes a much more important role in the discussion. And a transition of the electricity sector alone will be sufficient to drive peak demand for fossil fuels (but not the Paris Agreement). The math is not complicated. Falling fossil fuel demand in electricity generation (two-thirds of the growth in demand) needs to be higher than rising fossil fuel demand in all the other sectors (one-third of the growth in demand).

How Important are Solar and Wind?

What is the issue?

The issue is how to count solar and wind electricity (a high- quality energy carrier) as a share of global energy supply.[30] Because of thermodynamic losses, this is a real issue – the introduction of 100 MWh of solar will replace primary energy supply of 200-300 MWh of coal.

Gradual approach

The Gradual approach counts solar electricity in the same way it counts coal, without any adjustment. As a result, the new energy technologies of solar and wind appear relatively small. For example, the IEA implies that solar and wind electricity was just over 1% of global primary energy supply in 2017.[31]

Rapid approach

The Rapid approach seeks to adjust for the gap by multiplying solar and wind by a factor of 2-3 times when converting them into primary energy equivalents. For example, BP increases solar and wind electricity by 2.6 when turning them into Mtoe, and calculates that the share of solar and wind power in global primary energy supply is more than twice as large as the IEA estimates, at 2.6%.[32]

The gap between the two does not appear to be very material until the argument shifts to the change in supply. BP data show that solar and wind made up 27% of the difference in total energy supply in 2017. If current solar and wind growth rates of 15-20% are maintained, Carbon Tracker calculates that they will supply all incremental energy (not just electricity) in the early 2020s.[33] This makes them extremely material as agents of change.

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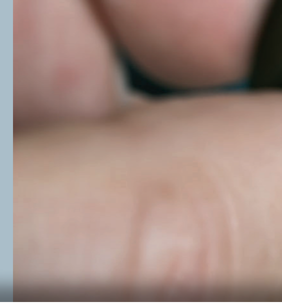


Differences Between Fossil Fuels

What is the issue?

The three primary fossil fuels, of course, are coal, oil and gas. Each is used in different applications in each of the world's countries, in a bewildering amount of complexity. The question is whether it makes any sense to talk about fossil fuels as a whole or look at each fossil fuel in each country separately.

Gradual approach

The Gradual approach is built upon highly complex models and seeks to model each end sector and each fuel in each country. The advantage of this method is that it enables forecasters to understand the impact of detailed changes.

Moreover, the argument is often made that the disruption striking the energy sector applies much more to coal than it does to oil and gas. Therefore, a coal transition rather than an energy transition affecting all fossil fuel sectors is being witnessed.

Rapid approach

The Rapid approach argues that it is necessary to take a more straightforward modelling approach at times of disruption. The technology and policy pressures that are being felt across the energy complex at present will affect all fossil fuels. And as technology improves, the fungibility between fossil fuels is also increasing (for instance cheap batteries make solar more fungible with oil to power vehicles at scale). Therefore, the peak in coal demand is likely to be the first of these peaks, to be followed by a peak in oil demand and eventually by a peak in gas demand. And as companies and financial investors see the pattern of these peaks, they will invest accordingly, which will in turn speed up the transition.

The Starting Point of the Two Narratives

These four issues mean that there are significant differences in the way the energy environment is perceived today, before the discussion on the future even starts.

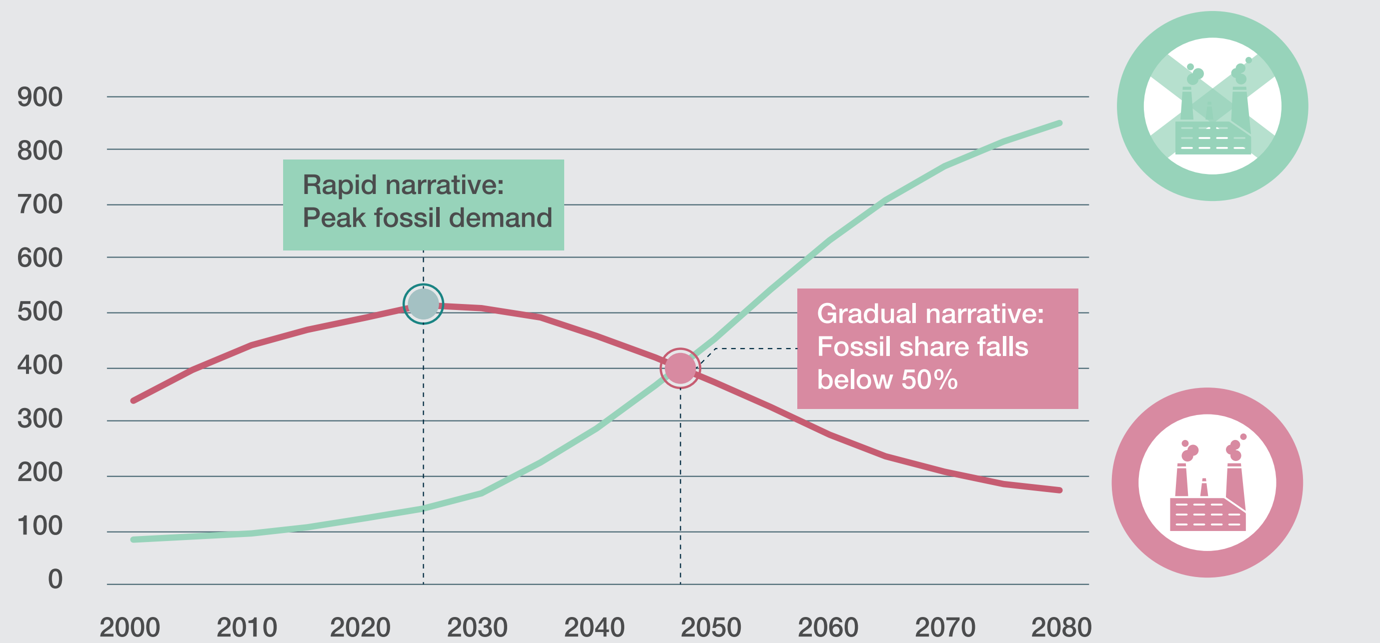
Gradual approach

Gradual advocates argue that the forces of disruption are small and therefore unlikely to have much of an impact.

They concede that changes are taking place in the electricity sector, but note that electricity is only 19% of total final energy consumption. Meanwhile, they argue that solar and wind are only 1% of total energy supply and electric cars are only 0.5% of the global car fleet.

They focus on the difficulty of providing renewable energy solutions in sectors like heat and petrochemicals and argue that developments in electricity are necessary but not sufficient. They note that in 2017, fossil fuels provided 81% of primary energy supply, and coal provided 38% of electricity, about the same as 30 years ago. It will take decades for renewable energy sources to become dominant in energy supply.

Figure 5: Global energy demand (EJ), 2000-2080



<u>Rapid approach</u>

Rapid advocates note that non-fossils provided 51% of the growth in global electricity supply in 201834 and 28% of the increase in global energy supply and that solar and wind are still increasing. Electricity is 38% of primary energy demand and will be two-thirds of the growth in primary energy demand as the world continues to electrify.

As a result, the disruption in the electricity sector will be sufficient to drive a peak in demand for all fossil fuels because declining demand in fossil fuels for electricity generation will outweigh rising demand for fossil fuels elsewhere in the energy complex.

<u>The gap</u>

We have to consider the difference between the importance and timing of the moment when the transition is felt. To illustrate this, Figure 5 shows the energy supply in the Shell Sky Scenario split into fossil fuels and non-fossils.

The Gradual narrative focuses on the point where non-fossils make up half of all supply. This, even under the Shell Sky Scenario, is not until 2050. Furthermore, advocates point out that even in 2100, the demand for fossil fuels is still quite high.

The Rapid narrative focuses on the point where non-fossils make up all incremental supply. This is in 2025, which is a generation earlier, and when non-fossils are just a quarter of total energy supply.

Advocates argue that the remaining amount of demand for fossil fuels in 2100 is hard to forecast with any certainty. The final areas of fossil fuel demand that may survive and will need to be replaced, but which are not enough to sustain the industry at its current size.

Technology Growth

Technology differences between the two narratives include the cost of existing new energy technologies, expectations for future technologies, the impediments to change and expected future growth rates.

<u>Cost of variable renewables in electricity</u>

The reason why variable renewable costs are so significant is that prices are the agents of disruption. In the discussion below, the focus is on the cost of electricity from solar. However, the story is similar for other disruptive technologies, such as wind, batteries and smart demand-side technologies.

<u>What is the issue?</u>

The question relates to what the costs of variable renewables are today and in the future. It might seem strange that there is dispute even over facts that are known, but this is indeed the case.

<u>Gradual approach</u>

The Gradual approach tends to be relatively conservative.[35] It takes peer-reviewed data (which is by definition, backwards-looking) and is cautious about future changes in costs.

For example, the IEA NPS argues that the Levelized cost of energy (LCOE) of solar in 2017 in the United States was $105 per MWh,[36] and that it would fall to $50 per MWh by 2040. Furthermore, the NPS argues that there are additional expenses for the deployment of solar (because of connection costs and intermittency costs), known as system costs, which make the real cost even higher. The total US cost of solar with system costs is calculated as $105 per MWh in 2017 (the same as without system costs) and $55 per MWh in 2040 (so 10% higher than without system costs).

<u>Rapid approach</u>

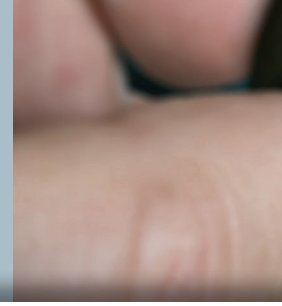
The Rapid approach tends to take forward-looking costs, to use actual projects37 and to be more optimistic about future cost falls. It is accepted that solar electricity costs have been falling at over 15% a year since 2009 and that solar modules have enjoyed a learning rate of 28% for every doubling in capacity.[38]

Advocates argue that it makes sense to look forward because of the speed of change and that costs are likely to continue to fall in line with the learning rate. They argue that the values used by the Gradual approach are demonstrably incorrect and that the Gradual approach fails to incorporate the cost of externalities.

Moreover, they note that many renewable technologies have enjoyed rapid cost falls thanks to learning by doing, the scale effect and the virtuous learning circle.

As costs have fallen, consumers have embraced the new technologies and governments have encouraged them, leading to lower costs and a new round of adoption. Hence, they argue that the growth should be modelled in a dynamic manner, not a static one.[39]

The upshot is that Rapid models have very different costs even for today. For example, BloombergNEF argues that the 2018 LCOE of solar in the United States was $42-65 per MWh, and it expects this to fall to $20-25 per MWh by 2040.[40]



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Rapid advocates note that system costs vary with the level of penetration of variable renewables and argue that they are unlikely to impose a significant burden on the cost structure for the foreseeable future. Even as penetration rises, technologies such as storage and demand response are likely to make higher levels of penetration cheaper. It is notable, for example, that solar plus storage projects are already starting to compete with fossil fuels in the United States.[41]

<u>The gap</u>

The gap between the two approaches is captured nicely by the actual and forecast US LCOE, according to the IEA NPS and BloombergNEF. The forecast IEA NPS 2040 solar costs are almost the same as the real average BloombergNEF 2018 cost (Figure 6).

New Technologies

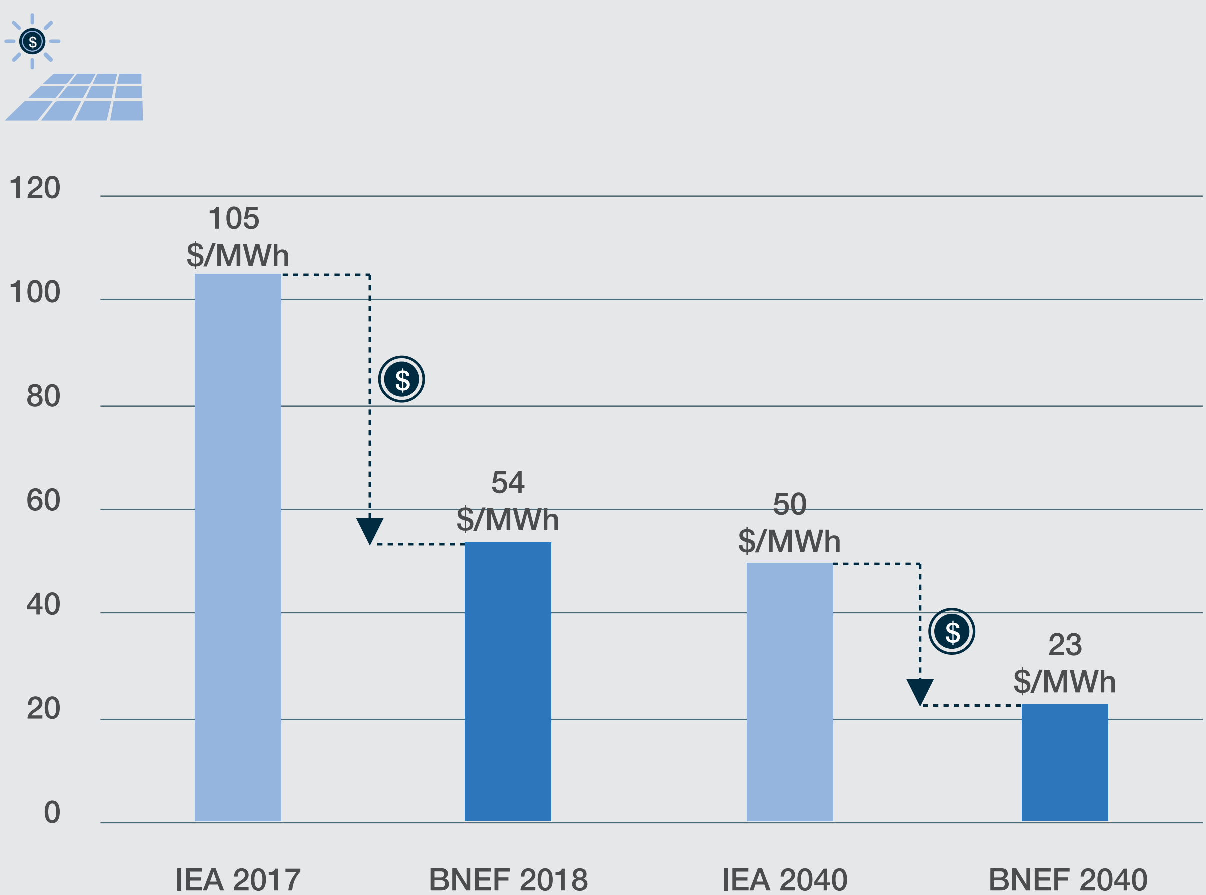
What is the issue?

The Energy Transitions Commission points out that existing new energy technologies will be able to accomplish much of the energy transition. However, improved technologies will be required to replace fossil fuels in hard-to-solve sectors, such as petrochemicals, airlines, winter heating or cement.[42] Investment is needed today for costs to fall, so these technologies are ready by the time they are required. The question is whether it is feasible and reasonable to forecast technology evolution.

<u>Gradual approach</u>

The Gradual approach is relatively conservative on the development of new technologies, preferring to focus on what is known rather than what may happen.[43] Advocates point out that the evolution of technologies is a complex and slow-moving process, requiring long lead times and significant amounts of capital. The implication is that these hard-to-solve areas not merely remain insoluble but

Figure 6: US solar (LCOE, US$/MWh)



will also grow. For example, most Gradual scenarios see rising demand for trucks and petrochemicals as the primary driver of rising oil demand over the next 20 years.

Rapid approach

Advocates note that energy technology developments over the last decade have already been rapid as technologies progressed on learning curves. In 2009, lithium-ion batteries cost over $1,000 per kWh and solar cost over $350 per MWh; by 2019, the cost of lithium-ion batteries had fallen to $160 per kWh and solar to $50 per MWh. Change has indeed been possible. The advocates use this to make three principal arguments:

- Current disruptive technologies, such as solar and batteries, continue on their learning curves. This will enable them to penetrate ever more sectors.
- Technologies will continue to evolve to allow deeper penetration of existing disruptive technologies. For example, variable renewable energy will be able to increase its share of the total electricity supply. Or electricity will be able to increase its share in the transport, heat and industry sectors. The speed with which companies are developing etrucks, and the many new solutions being put forward to reduce the demand for plastics are examples.
- New technologies will be designed to address the more intractable hard-to-solve sectors, such as petrochemicals or airlines. A series of solutions were put forward in the Energy Transitions Commission's Mission Possible publication. Meanwhile, the IEA notes that cheap solar can be used to create green hydrogen through electrolysis and that hydrogen can substitute for gas or oil in many areas of the energy system.[44]

This is not to say that a shift will be easy. Success will be the result of a combination of sound policies and technologies following learning curves. Not all renewable technologies have succeeded, and not all promising technologies will achieve.

Impediments To Growth

What is the issue?

The impediments to the implementation of the new energy technologies are the issue: at what point will technologies be unable to grow any further because of some insurmountable technological, economic or physical barrier? Social and political boundaries are dealt with in the next section.[45]

Gradual approach

Gradual scenarios tend to be relatively cautious regarding the difficulty of implementing new energy technologies. They have a wide range of concerns, including the lack of space for renewable energy technologies to be deployed; the challenges inherent in reaching 100% carbon-free energy; the problems of setting up EV infrastructure; or the lack of supply of various minerals, from cobalt to nickel to rare minerals.

Moreover, in many cases, the widespread adoption of new technologies proves prohibitively challenging to model with existing modelling practices. Current models are built to balance supply and demand in fossil-fuel-based markets, which are fundamentally distinct from emerging renewables and high asset-utilization service-based markets.

Rapid approach

Rapid models do not deny that impediments exist in most countries to implement 100% carbon-free energy. However, they make two observations: most countries are well below the feasibility ceiling, and it keeps rising as the result of the continued improvements in technology and emerging business models.

This can be illustrated concerning wind and solar. In 2018, solar and wind provided 7% of the supply of electricity globally, ranging from many countries with minimal amounts (in 27% of global electricity supply, solar and wind country penetration is under 5% and, in 94% of the total, country penetration is under 15%) to several countries with more than 25% solar and wind, and some regions with more than 50%.

Then, the feasibility ceiling is above 25%, and the IEA notes that there are phases in the process.[46]

Many examples of the rising feasibility ceiling exist. Innovations in electricity distribution systems have dramatically increased the feasible levels for the implementation of solar and wind, from under 5% some 20 years ago to over 50% today, and these systems continue to evolve.[47]

Outside the electricity sector, the picture differs, but the approach assumes that solutions will be found. In light transport, for example, there seemed to be many impediments to the growth of the EV. But as battery costs fall and expertise increases, range anxiety is diminishing as an issue. Meanwhile, it has become more likely that EV infrastructure will be rolled out as EV sales rise; some companies are now offering free home charger installation in return for access to the battery as a storage device.

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Meanwhile, economic impediments reduce as costs fall. It is possible to build marginal abatement cost curves to calculate the cost per tonne of reducing carbon dioxide emissions. The Global Commission on the Economy and Climate argues that when the co-benefits of an energy transition are taken into account, two-thirds of greenhouse gas emissions (25 gigatonnes (Gt) per year) can be eliminated at zero cost by 2030.[48] Without co-benefits, its analysis suggests that half the emissions can be reduced at zero cost.

As a result, advocates argue that the technological and economic impediments to the growth of renewables can be solved for the foreseeable future. No change is easy, nothing can be accomplished without effort, but that does not mean it is unachievable.

The gap

For each perspective, it is possible to show the ceiling of technological possibility graphed against today's levels of penetration. Neither view argues that the ceiling has been hit today.

The Gradual narrative explains that we will shortly bump up against it; the transition will peter out as the low-hanging fruits are plucked. The Rapid narrative argues that the ceiling is high above our heads and will continue to rise as the result of technological improvements.

The argument is illustrated in Figure 7 about solar and wind as a share of electricity generation with an illustrative depiction of the ceiling. Still, it could apply to many other sectors as well.

The Growth Rate of Existing New Energy Technologies

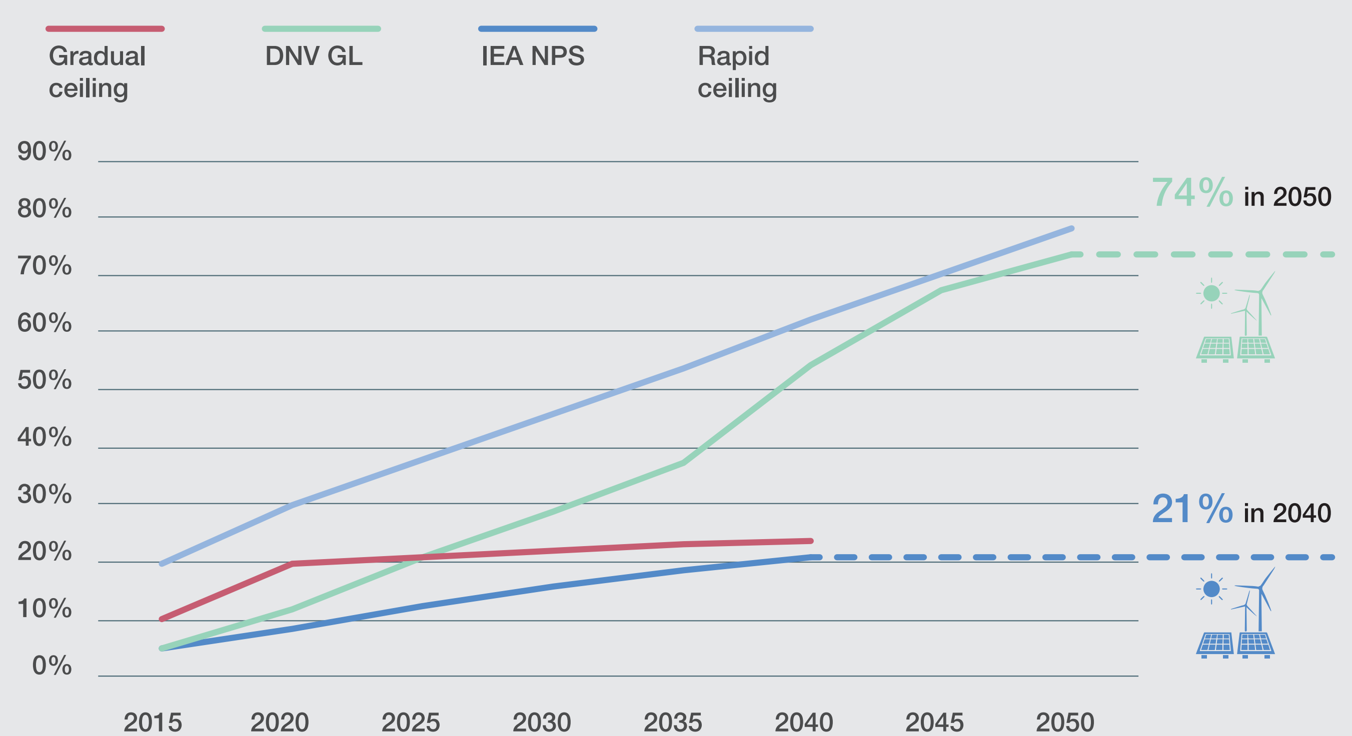
What is the issue?

Different assumptions regarding costs, barriers to growth and technology evolution drive very different projections of the growth rate of renewables. Will the growth rate of new technologies be linear or exponential?

Gradual approach

Gradual models assume that the renewable energy growth rate is linear. An example is the projection of annual installations of solar capacity in the IEA NPS. In the 2018 forecast, for example, it is assumed that solar panel installations will remain at around 100 gigawatt (GW) per annum until 2040 (Figure 8).

Figure 7: Solar and wind as a share of electricity generation and the ceiling level, 2015-2050



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"When I cast my mind back to why I decided to become a chemical engineer the overwhelming memory is one of excitement. I was going to get to build monuments, do projects, change the world. The reality is more exciting than I could have imagined. Can't wait to rub shoulders with other "can-do" engineers."

Melvin Jones

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Figure 8: New solar capacity (GW), 2018-2040

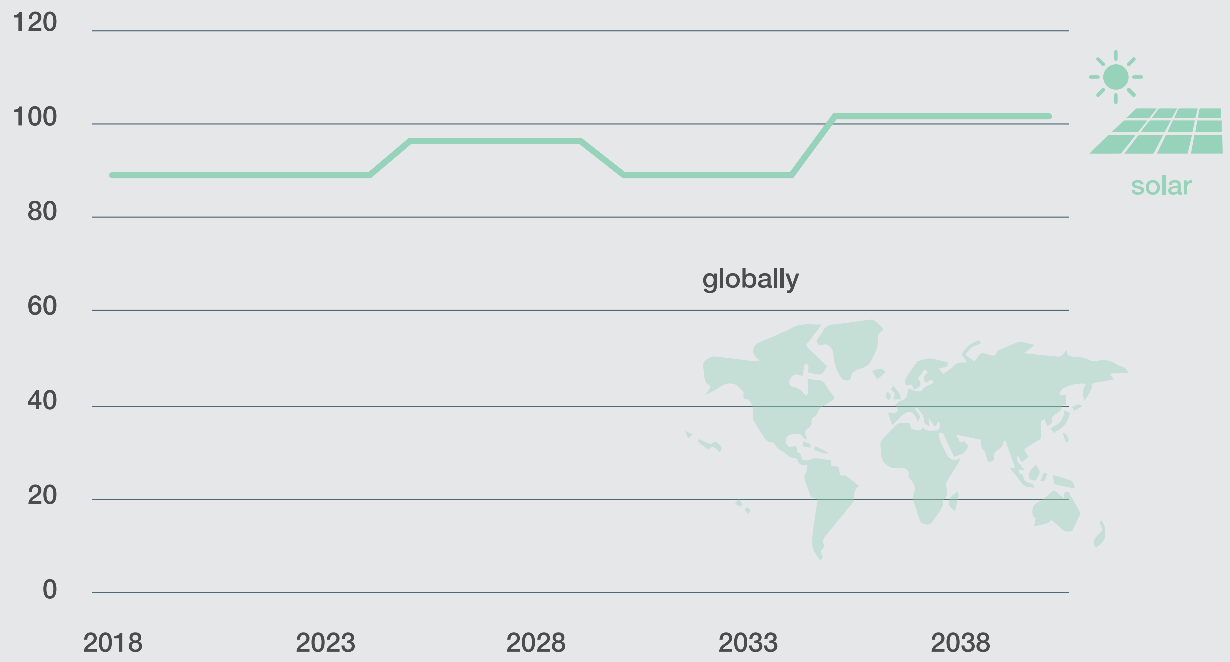
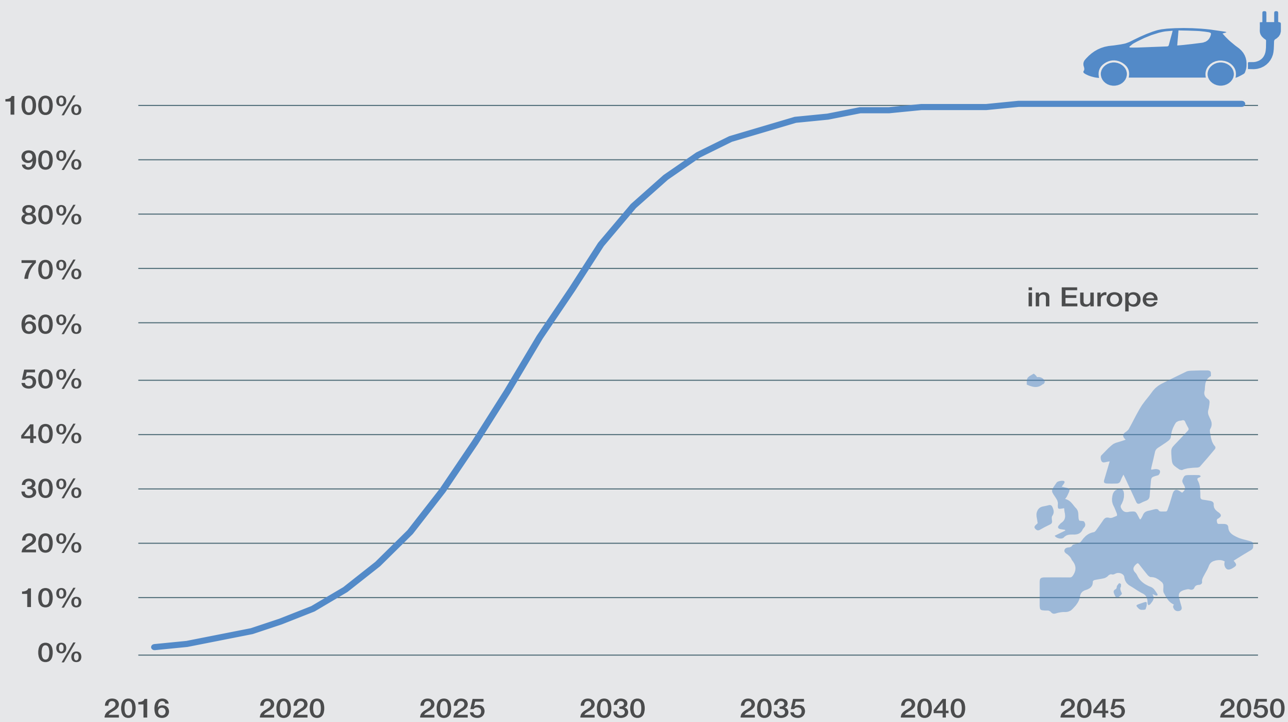


Figure 9: Market share of electric vehicles in Europe, 2016-2050



Rapid approach

Rapid models assume that renewable supply continues to rise on exponential S curves of growth. In an S curve, the market share of the new technology moves rapidly from 5% to around 90%, before slowing down. This is a phenomenon that has been seen in technology diffusion many times in the last century, from cars, radios and televisions to the mobile phone and internet in recent years. Advocates note that Gradual models failed to forecast the rapid growth of solar and wind for many years and that it is necessary, therefore, to adopt a different approach.[49] They point out that, even in 2018, the installation of solar panels (96 GW, according to BP) was much higher than the forecasts of standard Gradual models for 2018.

DNV GL, for example, forecasts the rapid growth of solar, wind and EVs along S curves. Sector specialists, such as IDTechEx, have a similar perspective.[50] This is illustrated in Figure 9 with the DNV GL forecast for the market share of EVs in Europe.

The gap

Different assumptions about the nature of growth lead to a massive difference between the two narratives. This is illustrated with the forecasts for electricity generation from solar photovoltaics (Figure 10). The IEA NPS forecast assumes slow linear growth, while the DNV GL forecast assumes exponential growth rates.

POLICY

Developments in technology are only one part of the energy transition. For change to happen rapidly, policies will need to better align the incentives of investors, businesses and individuals with the interests of society. And here again, a significant gap exists between the two narratives in terms of what can be expected from the policy.

Gradual models expect limited policy action, while Rapid models expect considerable policy action, encapsulated in the idea of an Inevitable Policy Response.[51]

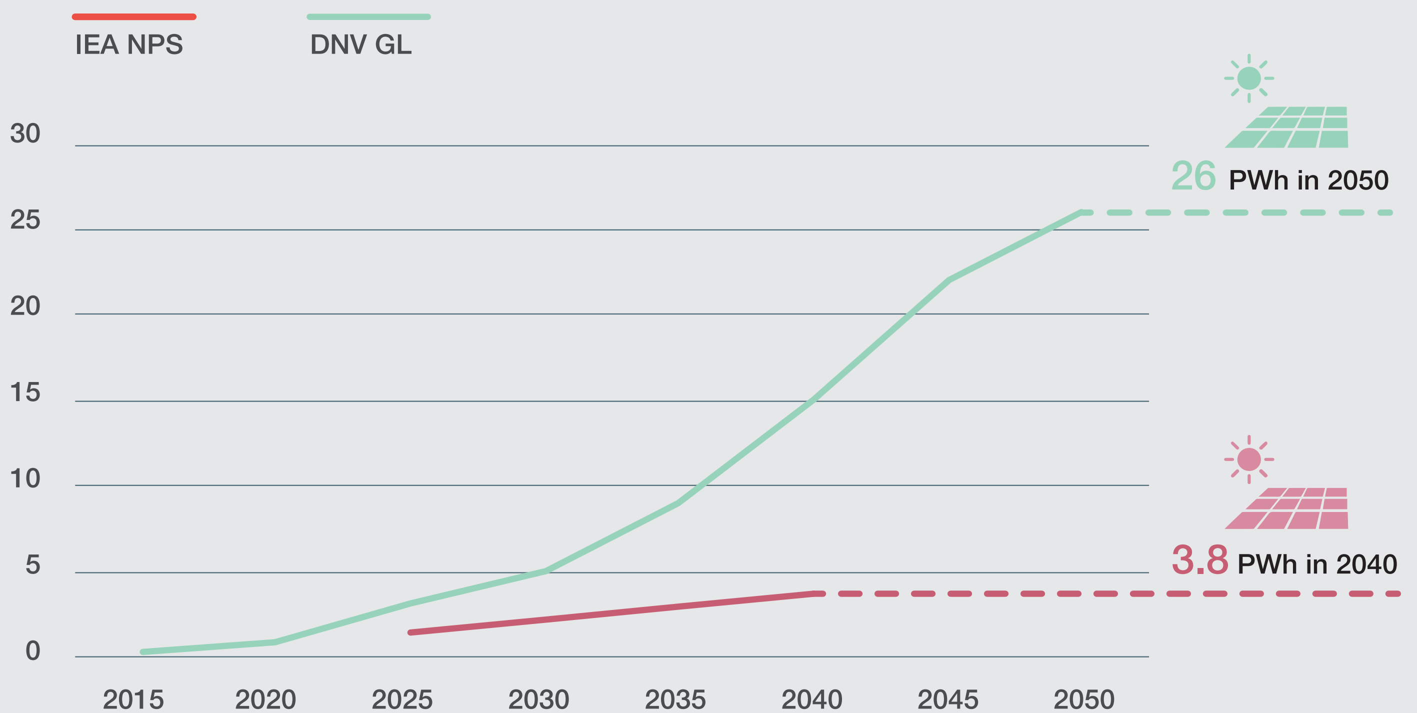
The two perspectives concerning the global balance of forces are summarized, followed by the country balance of forces.

The Global Balance of Forces

What is the issue?

First, a look at the global balance of forces. Many forces impact policy-makers. These include considerations on costs, jobs, health, global warming, geopolitics, pressures from civil society and the lobbying power of incumbents and beneficiaries of the fossil fuel system.

Figure 10: Solar electricity generation (PWh), 2015-2050



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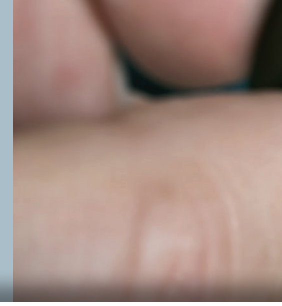


The IEA and IRENA have shown that the capital cost of an energy transition is similar to the cost of maintaining the current fossil fuel system.[52] Moreover, IRENA has been demonstrated that more jobs are required in a renewable system than a fossil fuel system.[53] However, a shift from one energy source to another would reduce rents flowing to the owners of fossil fuel assets (estimated by the World Bank to be around 3% of global GDP)[54] and could lead to stranded assets and communities if not handled sensitively. If these were the only considerations, then the power of inertia and lobbying would likely be able to maintain the status quo.

However, many further considerations are starting to impact decision-making.

- The cost of global warming, estimated by the Stern report[55] at 5% of global GDP with significant tail risks from feedback loops, and by Burke, Davis and Diffenbaugh at 15-25% of global GDP[56]
- The dramatic human costs of heat stress, disease and migration that are hard to quantify in GDP terms
- The impact on the health of outdoor air pollution (mainly from fossil fuels), estimated by the World Health Organization as killing 4.2 million people a year[57] and likely to double by 2060[58]
- The 1 million species at risk of extinction.[59]

When these are factored in, IRENA calculates that the benefits of an energy transition will outnumber the costs by 3-7 times.[60]

<u>Gradual approach</u>

The Gradual approach argues that policies that have yet to be approved should not be forecast, and points to the repeal of the Clean Power Plan (CPP) in the United States.[61] Moreover, the prospect of a rapid transition will create losers who want to maintain the status quo and feel relatively passionate about it. In certain countries, they can capture the government and use it to resist change.

Advocates note that even after a decade of pronouncements about the need to tax fossil fuels, the average global carbon tax per tonne is under $2.[62] Even if policy-makers ought to act, reality suggests that they will not.

<u>Rapid approach</u>

The Rapid approach notes that societal and financial forces for change are building, as seen in the rise of civil society pressure movements, such as Extinction Rebellion, and financial pressure groups, such as Climate Action 100+. Coal plants are still closing down in the United States because of economic pressures, in spite of support from the Federal government.

Advocates for this approach assume that policy will take advantage of new technological innovations to meet the aspirations of society. The falling costs of renewables have opened a window of opportunity for politicians to pursue green policies without imposing significant losses on society while garnering substantial public support.[63] The rising popularity of the Green New Deal is an example of such a political shift.

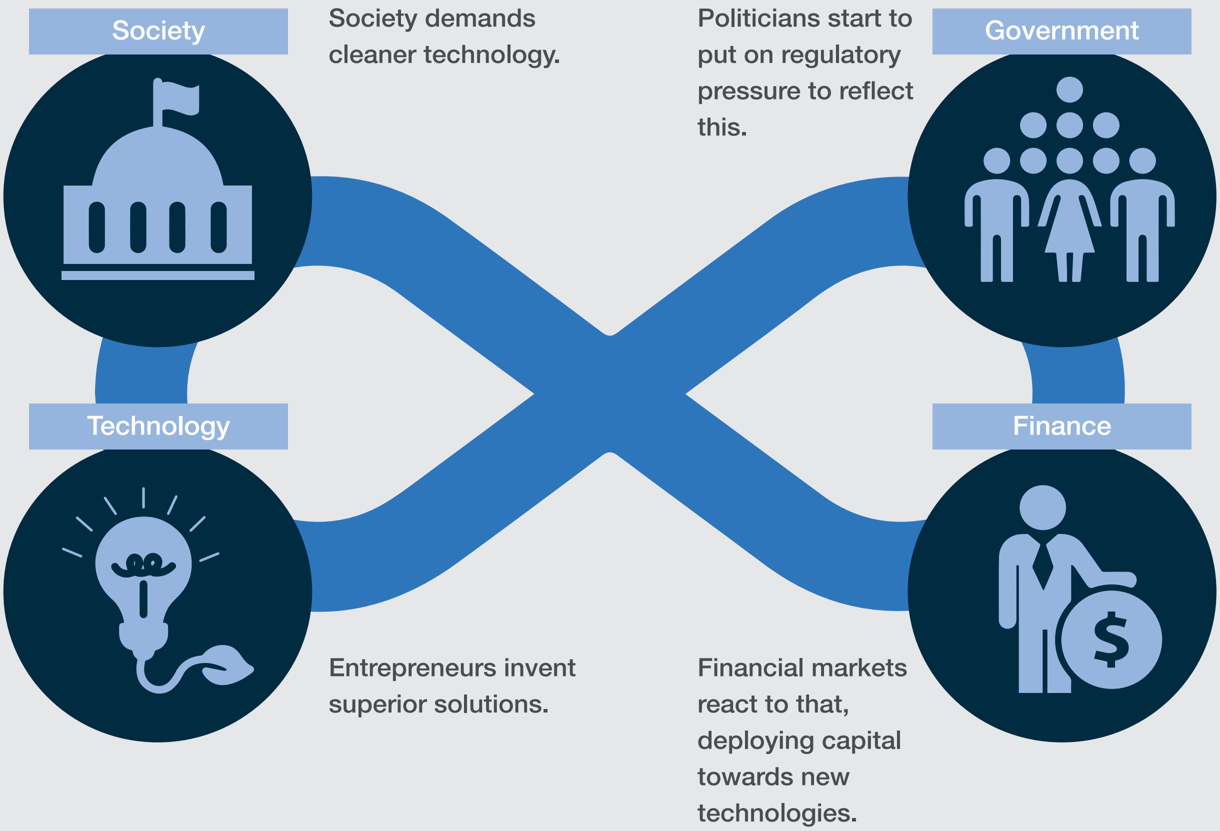
To quote the Committee on Climate Change: *"Once a technology becomes sufficiently competitive, it starts to change the entire environment in which it operates and interacts. New supply lines are formed, behaviours shift, and new business lobbies push for more supportive policies. New institutions are created, and old ones repurposed.*

As costs fall the political and commercial barriers to a transition, begin to drop away. A tipping point is eventually reached where incumbent technologies, products and networks become redundant."[64] That is to say, as the costs of renewables continue to fall, policy-makers will be able to react to the desire of voters to take action, and start to make fossil fuel users pay for their externalities.

Moreover, Rapid advocates argue that there is a positive feedback loop between government, technology, finance and society (Figure 11). Society demands cleaner technology and politicians start to put on regulatory pressure to reflect this. Financial markets react to that, deploying capital towards new technologies,[65] and entrepreneurs invent superior solutions. As these achieve grander scale, costs fall, society can afford more, politicians can legislate, and investors allocate more capital. Electric vehicles provide an excellent example of this positive feedback loop. They started as expensive toys for the rich, but rising sales are driving much lower battery costs and more aggressive policy action, and they are now becoming a mass-market product.

As a result, Rapid scenarios assume rising costs of carbon and falling subsidies for fossil fuel usage. Even if the policy cannot be forecast in detail, they argue it is reasonable to understand that policy will evolve, encapsulated in the idea of an Inevitable Policy Response. This is the moment when governments will be forced by the deteriorating environmental

Figure 11: The positive feedback loop



position to take more drastic action to curtail fossil fuel demand. They point to the increasing number of countries that target 100% renewable electricity by 2050,[66] and to individual states in the United States, such as California or Hawaii, which plan to move to 100% renewables.

The Country Balance of Forces

<u>What is the issue?</u>

Even if the global balance of forces may favour a transition, the picture can be very different at a country level. Although the situation is more complex, the first distinction to be made is between fossil fuel exporters (which may well resist a transition) and importers (who as a rule would benefit from it). There are, of course, exceptions to this framework. Japan is the world's second-largest fossil fuel importer but has so far been relatively supportive of the coal sector, and Norway is one of the world's more significant oil exporters but has embraced a transport transition.

<u>Gradual approach</u>

The Gradual approach points to recent developments in the United States and Australia as examples of countries where fossil fuel supporters have been able to take control of the political process and use it to hold back change.

<u>Rapid approach</u>

Advocates note that around 20% of the world lives in countries that are net exporters of fossil fuels, and 80% of the world lives in countries that are fossil fuel importers. So the geopolitical and societal advantage is aligned with reducing fossil fuel usage.[67] While incumbents may find it easier to prevent change in the energy exporters (such as Australia), they are likely to find it more challenging to do this in the importers of energy. And in the world's two largest countries of China and India, the imperative is clearly to reduce fossil fuel imports.

Emerging Market Energy Pathways

The emerging-market energy story is singled out for special treatment because it is key to any transition. In 2018, the average US citizen used 295 gigajoules (GJ) of energy, while the average Indian used just 25 GJ.

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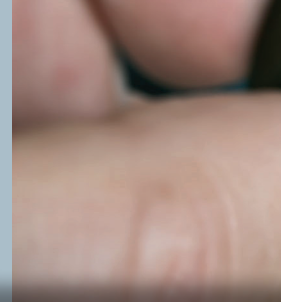


What is the issue

Energy demand in the OECD has been falling and is likely to continue to fall. Almost all growth in energy demand is expected; therefore, to come from emerging markets.

The implication is that developments in China and India are consequently more pertinent to the question of the change in energy demand than those in the United States and Europe.

The problem is whether these countries will follow the Western path of fossil-fuel-based development or take their energy path. Will countries like India or Viet Nam build their growing electricity systems on coal or on solar? Will they drive in ICE cars or EVs?

Gradual approach

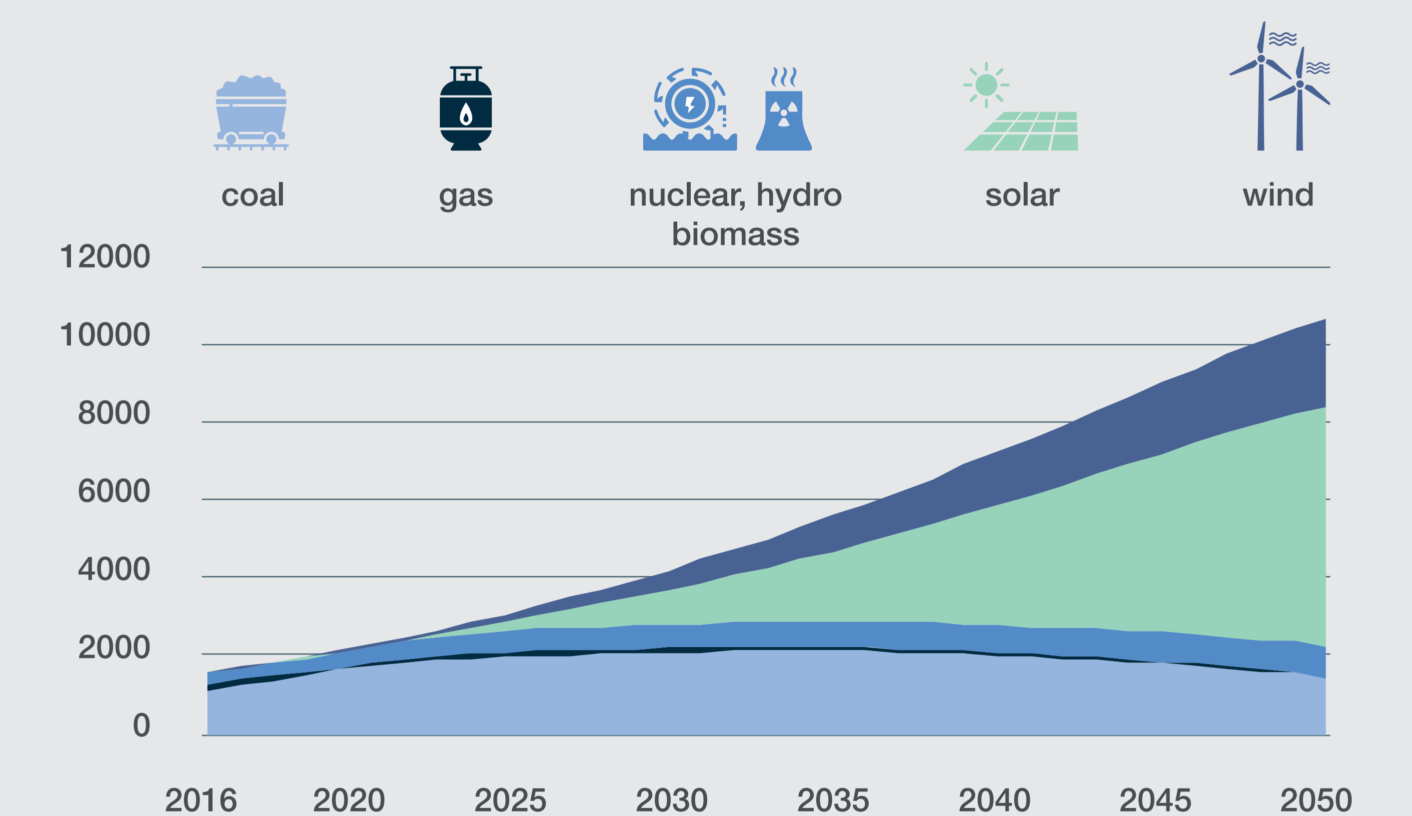
Gradual advocates assume that emerging market demand will mostly follow the pattern set by developed markets – the demand growth for fossil fuels will increase as GDP rises and people become richer.[68] These models can point to the fact that energy demand rises with GDP, which in the past has meant more demand for fossil fuels.

Rapid approach

Rapid advocates do not deny the legitimate aspiration of the world's energy-poor to enjoy the benefits of more energy. They simply argue that renewable technologies will supply this energy because they are cheaper, faster to implement, less polluting and use domestic fuel sources rather than imports. Moreover, they take into account the high level of pollution faced by countries, such as India where 140 million people already breathe air that is ten times more toxic than the level considered safe by the World Health Organization. Polluted air is responsible for the deaths of over 1 million people a year.[69] This provides extra incentive to the emerging markets to embrace energy technologies that cause less pollution.

These advocates argue that there will be an energy leapfrog, similar to that observed in mobile phones or banking services. They also claim, to a greater extent than the Gradual advocates, that the introduction of energy-efficient technologies will limit energy demand growth.

Figure 12: Electricity supply (TWh), Indian subcontinent, 2016-2050



Rapid advocates focus on developments in China and India, which between them are forecast to account for over half of the growth in global energy demand. In both China and India, solar electricity is now cheaper than that from fossil fuels, when comparing new projects in both.[70] Indian policy-makers, who only recently were mocked for having a renewable capacity target of 175 GW, recently raised it to 500 GW. As a result, models forecast that the share of electricity supply from renewables will multiply, as in Figure 12 from DNV GL for the Indian subcontinent.

A similar story can be told in transport. Higher domestic petrol prices and lower driving distances (hence smaller battery requirements) than in the United States meant that EVs in China has already crossed the fundamental 5% market-share penetration level, and the demand for ICE cars is already falling.

IMPLICATIONS OF THE TWO NARRATIVES

With different modelling, assumptions come to different conclusions. This focus is on three: the likelihood of achieving the goals of the Paris Agreement; the timing of peak fossil fuel demand; and the significance of peaking demand.

The Road To Paris

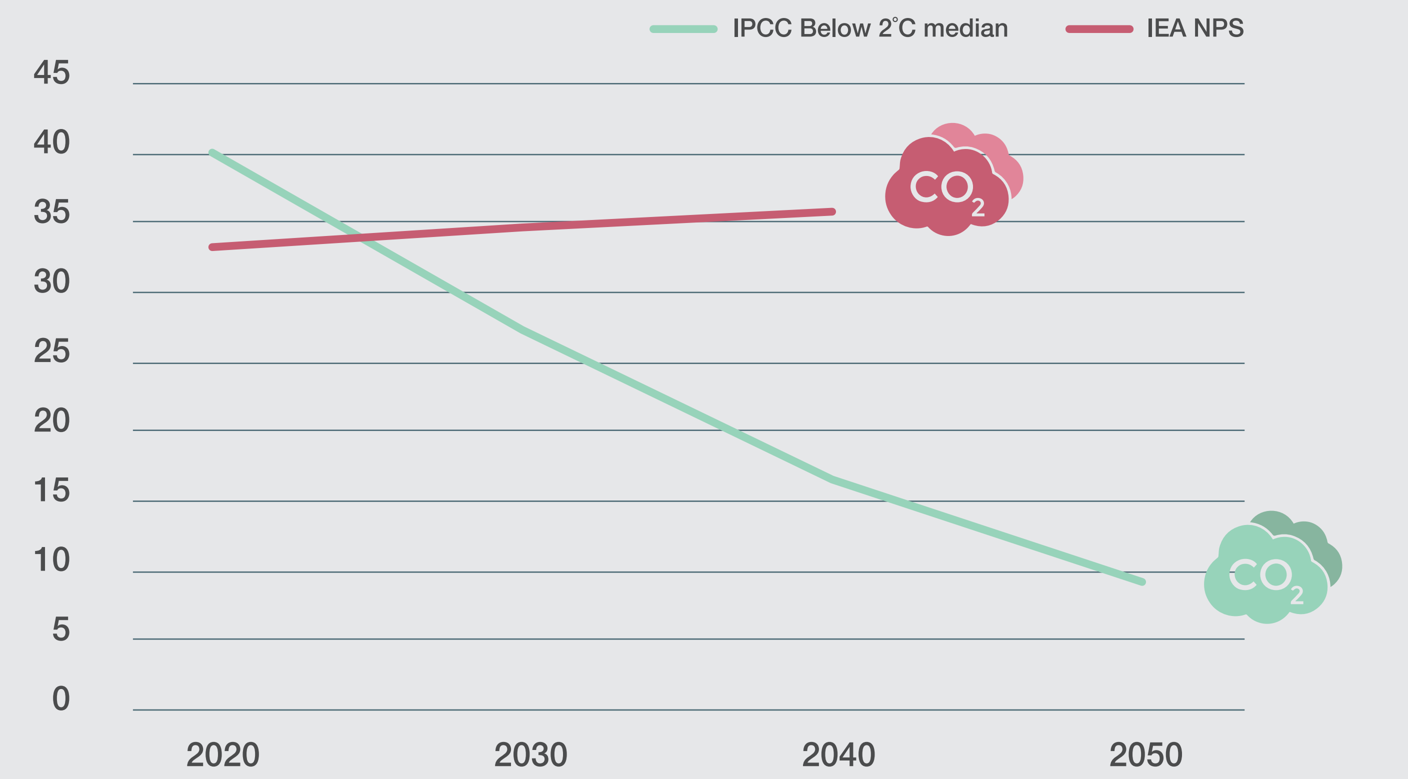
The central aims of the Paris Agreement are to strengthen the global response to the threat of climate change by keeping the global temperature rise, this century, well below 2 degrees Celsius - compared to pre-industrial levels, and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

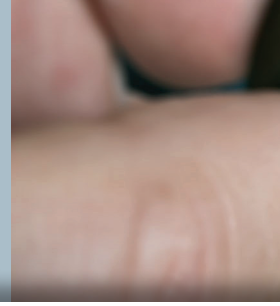
Gradual scenarios have rising emissions, implying that they will be unable to achieve the goals of the Paris Agreement.

Rapid scenarios have a peak in emissions in the 2020s. This means that they provide a foundation to achieve the goals of the Paris Agreement.

The gap between the two narratives is captured by the expected carbon emissions under the IEA NPS and those required to reach 2 degrees, as summarized by the IPCC (Figure 13).[71]

Figure 13: CO_2 emissions (Gt), 2020-2050





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When Is Peak Fossil Fuel Demand?
The difference between the two narratives on the timing of peak fossil fuel demand is profound.

Gradual scenarios do not foresee peak fossil fuel demand for another generation. Peak demand for fossil fuels is out of the forecast range of models such as the IEA NPS, the BP ETS and those of Exxon, and is not expected until after 2040.

Rapid scenarios foresee peak fossil fuel demand in the 2020s. DNV GL and McKinsey, for example, expect a peak by 2028, and the Shell Sky Scenario by 2025.

How Significant Is Peak Demand?
Narratives differ dramatically on the significance of peak demand.

Gradual scenarios imply no significant threat to the fossil fuel sector incumbents from peak demand. This is in part because they do not see a peak for many years, and in part, because they argue the decline will be slow after the peak. After all, the market will still require fossil fuels for many years.

Rapid scenarios, in contrast, imply that the fossil fuel sectors will be disrupted by the transition from growth to decline if they do not adapt quickly. They point to the experience of the European electricity sector, the global coal sector, the gas turbine sector and the auto sector. All in recent years have faced disruption when challenging technologies have had a small market share but have captured the growth in the market. For example:

- The European electricity sector lost over half of its capitalization in the decade after the demand for fossil fuels stopped growing.
- Half the US coal sector went bust when global coal demand fell just 4% from its all-time high.
- GE lost two-thirds of its capitalization in 2018 after it had to take a significant write-down on its turbines division.
- The global auto manufacturers have been underperforming as they struggle to come to terms with a new environment.

And as a result, they expect a significant impact on incumbents in the fossil fuel sectors from peaking demand in their core markets if they do not adapt quickly.

However, recent history has also shown that many incumbents, especially in the electricity sector, have been able to change business models and investment strategies to take advantage of new opportunities centred more around energy services to customer, renewables and the digitalisation of energy.

CONCLUSION: WHAT TO WATCH OUT FOR

At the time of writing, it is not yet clear which narrative is likely to prevail. It's difficult for complex models to forecast systemic change because developments beyond ten years are tough to predict with any accuracy in three areas in particular: technology, policy and society. These are the three focus areas in the energy transition.

Indisputably, growth occurs in some areas and decline happens in others; the question is how they balance. Ultimately, the path to be taken will depend on a complex series of growth and decline rates. Outlined below are recent developments that are used by advocates on the two sides of the debate as well as some of the critical factors to help establish which path the world is following.

Recent Developments
Gradual approach
Gradual advocates point to several recent factual events to support their narrative:

- **Energy demand growth.** High energy demand growth occurred in 2018 (2.3%), significantly higher than in the previous few years.
- **Growth of the hard-to-solve sectors.** Demand is rising from petrochemicals and airlines. These sectors appear to have few renewable alternatives.
- **Peaking renewable supply.** Data suggests that solar and wind capacity installations in 2018 were similar to those in 2017, implying that growth rates may have peaked.
- **Insufficient renewable investment.** Investment in renewable capacity is not growing as rapidly as is necessary to achieve the goals of the Paris Agreement.72
- **Policy rollback.** Environmental protection in the US under the Trump administration has decreased, and US energy demand has increased.
- **More coal.** Coal-fired power stations are still being built, and coal demand rose in 2018.
- **Not enough success.** The IEA tracks progress across 45 clean energy technologies, highlighting that growth is only on track in 7 of the 45 areas to hit the targets of the Paris Agreement.[73]

Rapid approach
Rapid advocates point to a competing set of facts:

- **Peaks have begun.** Disruption is already happening, but not widely distributed. Each year sees peaking demand for fossil fuels in some applications within countries. For example, ICE demand may have peaked in 2018 in China, and

the automotive sector has transformed its strategy accordingly, pledging $300 billion to EV strategies.

- **Cost falls continue.** The cost of new energy technologies (especially solar and batteries) has continued to fall rapidly to levels below the price of fossil fuel technologies.
- **Rapid renewable growth continues.** EVs, batteries, solar and wind energy continue to exhibit exponential growth. This is in spite of the slowdown in investment because costs are still falling.
- **Some policy-makers are acting.** Global carbon taxes increased by one-third in 2018 to $44 billion,[74] and state and city action has shifted to 100% renewable energy and enacted bans on certain types of ICE cars. This is happening from California to Hawaii, from Paris to Berlin.
- **Fossil fuel CAPEX is low**. Final Investment Decisions (FID) on coal-fired power stations are down by 75% in the last five years and are tracking seven years ahead of the expected levels in the IEA NPS. Meanwhile, oil and gas CAPEX is in line with the IEA SDS.
- **Societal pressure is rising.** Public concerns about the impact of global warming and pollution are rising, as manifested by Greta Thunberg and the rise of Extinction Rebellion.
- **Finance is mobilizing for change.** This is demonstrated by the success of the CA100+ movement and the growing calls for disclosure from the Task Force on Climate-related Financial Disclosures (TCFD).

Technology

Issues to focus on to determine if a Gradual or Rapid narrative is playing out in coming years include:

- **Cost of solar, wind and batteries.** These technologies are essential because they are large enough to have a material impact, they are already challenging fossil technologies on price, and they are on well-established learning curves. Will costs continue to fall at learning rates of around 20%? If so, generation costs from solar by the end of the decade will be so low that it will be possible to use solar electricity to make hydrogen economically via electrolysis in some countries. And battery costs will be so small that it will be possible to reduce the variability of solar and wind dramatically and increase still higher their ceiling of penetration. The key numbers to focus on for 2030 would be solar and wind costs of $20-30 per MWh and battery costs of $50-100 per kWh.
- **The growth rate of solar, wind and EVs.** Will these technologies remain on their S curves of growth? If so, they will start to supply all net new generation capacity by the early 2020s and will start to replace existing fossil fuel plants later in the same decade. By 2030, Rapid models expect to see over 300 GW a year of solar and wind installations and global EV market share of at least 30%.
- **Electrification.** Will electricity continue its march into other sectors? A Rapid transition would need growth in the share of electricity to be at least 3-4 percentage points per decade.
- **New renewable technologies.** Will other new technologies arise that can change the story dramatically? Those to watch, include green hydrogen, pyrolysis and next-generation biofuels.
- **Other energy technologies.** Of course, the potential exists for significant cost falls in carbon capture and storage, which is technically available and has many leading pilot applications at scale. With the right policy support, the technology may also enjoy learning curves. Separate to this, an enduring hope is nuclear fusion, and breakthroughs may occur in other areas. These could also alter the energy mix dramatically.

Policy

Areas to focus on include:

- **Efficiency.** Governments have a pivotal role to play in the promotion of efficiency,[75] through regulation on building codes, cars, appliances, and so on. Efficiency levels rose to over 2% in the years before 2017, before falling back to 1.3% in 2018, according to the IEA. The rapid change would be much easier if efficiency were to rise to over 2%, driving down global energy demand growth to around 1%.
- **Carbon taxation.** Will policy-makers seize the opportunity of falling new energy technology costs to implement much more aggressive regulatory regimes to tax fossil fuel users for their externality? The two key metrics to focus on are the phasing out of support for fossil fuels and the widespread imposition of carbon taxes. IEA and IRENA have shown that even a relatively low carbon tax would be sufficient to make around half the world's emissions uneconomic.[76]
- **Electrification.** Support for the electrification of the rest of the energy complex is needed, including heat, transport and industry.
- **The emerging-market energy leapfrog.** Attention must be paid to the policy direction being set by the world's largest growth markets, such as China, India and South-East Asia. Within these markets, whether coal is being

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substituted by solar and whether EV sales are moving up an S curve of change. Recent examples of this include the growing number of cancellations of coal-fired power stations across Asia as well as the breakthrough of EV sales through the critical 5% market- share penetration level in China.

- **The just transition.** Can governments devise ways to mitigate the pain of the energy transition for those individuals and communities most impacted?
- **The policy ratchet.** The Intended Nationally Determined Contributions submitted to Paris imply global warming of 2.7 degrees Celsius, and several countries are already failing to hit their Paris commitments. By 2030, liabilities would need to be ratcheted much closer to 2 degrees Celsius.

Milestones for 2030

The intention is not to be drawn into a scenario debate, but, it is useful to give a sense of the gap between the two narratives. Therefore, some pointers are summarized below that help to indicate the current path; clearly, not all targets will be reached, but a dominant narrative will likely emerge over the decade. The focus is on the year 2030 to give a sense of what needs to happen over the next decade for the Rapid narrative to be credible. Concentration is on a limited number of factors that are easy to monitor.

The Price of Solar Electricity in 2030

Under the Gradual scenario, solar prices are likely to stop falling rapidly, and average global rates will be at $50-70 per MWh in 2030. Under the Rapid scenario, they would fall to the $20-30 level, at which point they start to impact many other sectors.

Solar Capacity Installations in 2030

Under the Gradual scenario, solar capacity installations would stay at levels similar to today, around 100 GW per annum. Under the Rapid scenario, solar installations would rise to well over 200 GW per year.

EV market share in 2030

Under the Gradual scenario, EVs would increase its market share to around 5-10% of sales by 2030. The Rapid scenario would see them taking a market share of over 30%.

Carbon taxes

In 2018, the World Bank calculated total global carbon taxes to be $44 billion,[77] so under $2 per tonne for the 37 Gt of carbon dioxide emissions in that year. Only 20% of emissions are priced at all, and only 5% are rated at a level consistent with the Paris Agreement.

Under the Gradual scenario, taxation would increase a little, but the difference would not be dramatic. Under the Rapid scenario, the policy response would be much more aggressive, which would see a dramatic increase in the share of emissions subject to carbon pricing and a significant increase in the level of taxation. It is hard to put a number on this, but the level of action that would be needed is around half of the emissions being taxed at average tax rates of around $20 per tonne taxed.

Peak demand

There are then three specific peaks that distinguish the two narratives. The Rapid narrative would see peaks in these areas in the 2020s; the Gradual narrative would not.

- Peak demand for new ICE cars
- Peak demand for fossil fuels in electricity
- Peak demand for fossil fuels in total. wn

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SAIEE

Potentials of locally manufactured wind generators in SA

The China-based monopoly of high-energy permanent magnet materials, used in modern wind generators, impact the economic viability and local content value of most wind turbines installed in South Africa, especially in large installations. It is possible to design, with less expensive excitation technologies, using locally-sourced wound-field electromagnets, which might promote local content.

BY | U. B. AKURU
M. J. KAMPER

This study involves the optimum design performance comparison of the wound-field flux switching machine (WF-FSM) technology based on two variants – Design I and II (D-I and D-II) – the difference being in the arrangement of their DC wound-field coils. The machines are evaluated using finite element analyses (FEA) with optimum performance emphasised on design parameters such as torque density, efficiency and power factor. The selected design targets are meant to improve the performance to cost fidelity of the proposed wind generator variants. In 2D FEA, D-II can produce up to 18.8% higher torque density (kNm/m^3) and 17.1% lesser loss per active volume (kW/m^3) than D-I. In 3D FEA, the torque density of D-II remains higher at 10.6%, but its loss per active volume increases by 15% compared to D-I. The discrepancy observed in 2D, and 3D FEA is due to an underestimation of the end-winding effects in D-II. The power factor of D-II is higher than D-I, both in 2D and 3D FEA, which may translate to lower kVA ratings and inverter costs. A higher total active mass ensues for the studied WF-FSMs than a conventional direct-drive PMSG, but avoiding rare-earth PMs translates to significantly lower prices. The latest global status report on renewable energy indicates that wind power led global renewable capacity for the third year in a row, with a cumulative installed total of 539 GW – 24.5 % of the world total[1]. The same report shows that South Africa ranked among the top counties in Africa for cumulative non-hydropower renewable energy capacity as at the end of 2017. Furthermore, it remains the only African country to have commissioned wind power projects in 2017[1], while also being the topmost in Africa for installed wind power capacity at 1980 MW, along with an estimated cumulative capacity of 11 442 MW by 2030[2]. To meet its planned renewable energy targets, South Africa has benchmarked, among other things, affordable electricity and technology localisation as key objectives of its draft Integrated Resource Plan 2018[2].

A vital component of the wind turbine architecture is the wind generator. It is commonly taken that doubly-fed induction generators (DFIGs) are the workhorse wind generators in the wind power industry[3]. But with the advent of bigger direct-drive wind turbines, permanent magnet synchronous generators (PMSGs) are becoming increasingly relevant due to their propensity for improved torque

density designs and operational efficiency performance[4,5]. However, with the growing popularity of PMSGs comes the high cost of rare-earth PMs, facilitated by a monopolised market structure, with recent impulsive price swings, is one reason for current alternative non-PM solutions - so-called rare earth-free wind generator technologies[5].

The PM flux switching machine (PM-FSM) has been commercialised for 3 MW wind turbines[6]. FSM is a re-emerging class of double-salient machines with stator-mounted and robust rotor features which makes it suitable for particular drivetrain applications[7,8]. Just like synchronous machines, FSMs can be excited with PM (e.g., PM-FSMs) or DC wound-field coils such as wound-field FSMs (WF-FSMs). Importantly, the design and operational characteristics of the WF-FSM topology is unlike its conventional wound-rotor synchronous machine (WRSM) counterpart. It does not require slip rings and brushes for its DC field current excitation. To this end, the reliability of WF-FSMs is improved.

In South Africa, manufacturing and installation of wind turbines translate to premium on the imported raw materials or technology, at least, of the rare earth PMs mostly deployed in such designs. Based on estimations, 23% of global installed wind turbines use PMSGs, which are designed with rare-earth elements[5].

Therefore, for large wind turbines, the PM content mass, implying cost, will increase as the power level increases, especially for direct-drive wind generator systems as illustrated in Figure 1[5,9]. To this end, there is the possibility of designing wind generators with cheaper excitation technologies such as wound-field (WF) electromagnets which can be locally produced. This way, the localisation drive of wind power infrastructure could be enhanced in the long run.

While a 300 kW direct-drive PMSG has been fully developed and presented for the South African wind power industry[10], none which uses non-PM technology has been reported. This study involves the semi-optimised design of the FSM technology based on two proof-of-concept wound-field variants, shown in Figure 2 as Designs I and II (D-I and D-II for short), at 300 kW power levels. The prescribed power level of the proposed wound-field machines is the so-called medium-scale power range[9]. In Figure 2, the DC coils of D-I overlaps transversally across the adjacent armature coils. At the same time, that of D-II displays a parallel overlap winding array between the DC and armature coils.

An exhaustive characterisation of the design concept shown as D-I has been undertaken by the authors for both rare earth and rare earth-free wind generator applications, at different power levels[11].

Although D-II is a well-established WF-FSM design concept, there is no explicit consideration of it as wind generator designs, not to mention the authors' ignorance of any comparison existing between the designs. Over and above, the WF-FSM generator concept is nominated for this study because, unlike the WRSM, it possesses a brushless DC excitation scheme and robust rotor topology.

Wind Generators

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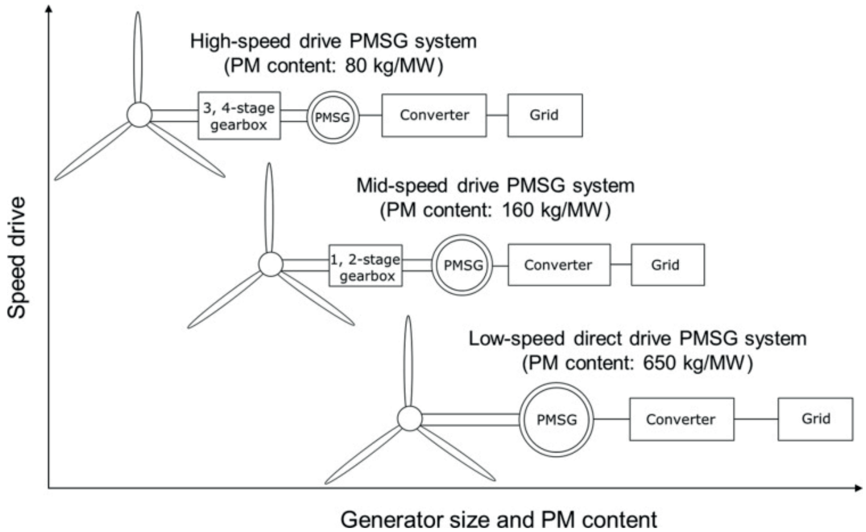

Figure 1: Wind turbines designed with PMSGs[5].

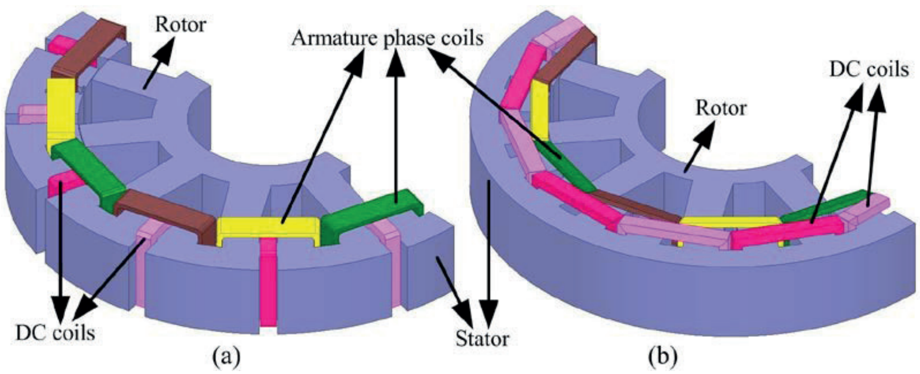

Figure 2: Presentation of the selected WF-FSM designs: (a) D-I, and (b) D-II.

The proposed machines are primarily evaluated using finite element analyses (FEA) with optimum performance emphasised on design parameters such as torque density, efficiency and power factor, among others. The study is patterned similarly to that performed by Potgieter and Kamper[9], and so makes no promises on the mechanical and thermal fidelity of the design process. The selected design targets are meant to improve the electromagnetic performance to cost index of the proposed generator variants for a medium-speed wind energy drive system, as shown in Figure 1. At the end of the study, an existing 10 kW manufactured prototype of D-I is experimentally reported to validate the results.

Meanwhile, a possible limitation may occur in the initial results of the studied machines at 300 kW because of the end-winding formulation assumed in the 2D FEA procedure. Besides, because of the 2D nature of the initial static FEA results, the level of magnetic saturation cannot be ascertained, but in 3D transient FEA. Thus, any such doubts initially accruing from the 2D FEA solutions have been clarified based on the 3D transient FEA calculations, also undertaken in this study.

OPTIMISATION PROCESS

As already mentioned, two WF-FSM variants are benchmarked and initially designed to achieve the reference generated output power (P_g) at 300 kW. The machines are designed with a robust static FEA tool developed in-house, the so-called SEMFEM package[12], which speeds up the simulation time while maintaining reasonable accuracy on the solutions. After obtaining the reference design, the optimisation design is set up and interfaced to the FEA models using a commercial optimiser (VisualDoC[13]), as shown in Figure 3. The optimisation is based on a simple gradient approach called the modified method of feasible directions (MMFD). The optimisation problem is then processed as follows:

Minimise:	M_{Tot}	(1)
Subject to:	$P_g \approx 300\ kW$	(2)
	$PF \geq 0.8$	(3)
	$\eta \geq 95\%$	(4)
	$\Delta T_L \leq 10\%$	(5)

where (M_{Tot}) is the total active mass, (PF) is power factor, (η) is efficiency and (ΔT_L) is the peak-to-peak torque ripple at rated load.

A total of 14 design parameters were nominated for D-I, and 13 for D-II. In each case, the design parameters include both dimensional and non-dimensional variables, such as stator outer diameter (D_0), stator inner diameter (D_i), stack length (l), armature current density (J_s) and wound-field current density (J_{ec}), to mention a few. The present thicknesses have been varied to ensure that reasonable

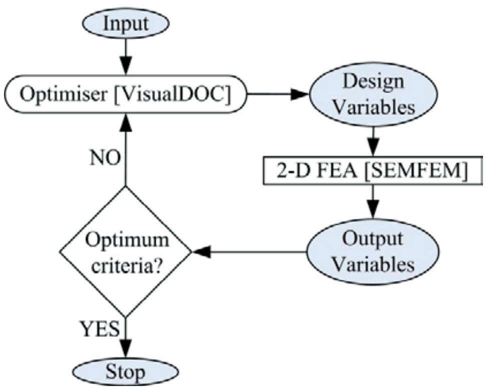

Figure 3: An illustration of the design optimisation procedure.

Figure 3: An illustration of the design optimisation procedure.

thermal limits are respected in the final designs, even though a failsafe thermal analysis is not an objective in this study. The airgap (g), slot filling ratios of the wound-field DC (K_{ec}) and armature (K_s) winding slots, as well as rated generator speed (NS), among others, were kept constant. After defining the design parameters, some additional formulations, necessary for the optimisation process, were implemented to describe realistic boundary conditions and were kept as similar as possible for both designs. On completion of the optimisation runs, the final designs were collected and compared, as discussed in the following section.

RESULTS AND DISCUSSIONS

The results of the 2D FEA optimisation process are presented in Tables 1 and 2. As indicated, most of the design targets were achieved, especially for D-II. After several optimisation-runs, it was proving difficult to realise the efficiency prescription for D-I without exceeding the logical limits of the defined design optimisation space. It is not a surprising occurrence, especially given that the compared evaluated total conductor losses (P_{cu}) shows that the specific DC conductor losses of D-I is 13.03 kW. At the same time, that of D- II is a mere 8.64 kW, which is because the same slot filling factors (K_s and K_{ec}) were assumed for both designs in 2D FEA. On closer inspection of the slot designs, such an assumption is naturally more profitable to D-II than to D-I, as shown in Figure 4. Also, the end-winding effects might have been poorly attributed in D-II, thus resulting in smaller conductor losses.

Another observation in D-I which can be associated with its end-winding evaluation is the recorded lower power factor, which should inherently yield more significant leakage reactance compared to D-II. To this end, D-II is seen with a higher power factor, which may imply lower kVA ratings and inverter losses (costs), and higher generator overload capability. Furthermore, it is observed that D-II yields 18.8% higher torque density (kNm/m^3) and 17.1% lesser loss per active volume (kW/m^3) than D-I.

Meanwhile, note that Tables 1 and 2 also display the performance data of a 300 kW optimum conventional direct-drive PMSG as evaluated in Potgieter and Kamper[9]. The performance of the PMSG is carefully contrasted against that of the studied WF-FSM variants designed in the medium-speed drivetrain. It is observed that the active masses (M_{Tot}) and torque density (T_r/V_{act}) of D-I and D-II is much higher than

Table 1: Optimum performance data of 300 kW wind generators.

	$\Delta\tau_{NL}$ (%)	$\Delta\tau_L$ (%)	P_{cu} (kW)	P_{core} (kW)	PF -	η (%)	T_r (kNm)	M_{EFS} (kg)	M_{Cu} (kg)	M_{Fe} (kg)	M_{Tot} (kg)	P_{loss}/V_{act} (kW/m^3)	T_r/V_{act} (kNm/m^3)	P_g (kW)
D-I	7.85	8.76	15.63	3.16	0.79	94.15	9.52	74.5	61.3	2 183.5	2 319.3	41.38	20.86	303
D-II	6.62	5.56	10.52	2.32	0.98	95.91	9.43	63.9	63.9	1 744.3	1 872.1	34.29	24.79	302
PMSG	5.30	25.74	13.30	2.46	0.95	95.00	67.00	114.6	282.3	967.0	1 363.9	12.11	52.50	300

Table 2: Optimum design data of 300 kW wind generators.

	J_s (A/mm^2)	J_{ec} (A/mm^2)	n_s (r/min)	f_s (Hz)	l (m)	D_i (m)	D_o (m)	g (mm)	k_s -	k_{ec} -
D-I	3.50	7.62	300	50	0.37	0.90	1.25	2	0.45	0.45
D-II	3.33	7.29	300	50	0.38	0.79	1.12	2	0.45	0.45
PMSG	4.58	-	50	114.6	0.26	2.43	2.5	-	-	-

Wind Generators

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Table 3: Cost analyses data of 300 kW wind generators.

	EFS (USD)	*Cu* (USD)	*Fe* (USD)	*Total* (USD)
D-I	834.4	686.6	4 803.7	6 324.7
D-II	715.7	715.7	3 837.5	5 268.9
PMSG	6 876	3 161.8	2 127.4	12 165.2

that of the PMSG. Also, in terms of the P_{loss}/V_{act} index, the value for the PMSG is significantly lower than those conceived in the WF-FSM designs. As noted in Potgieter and Kamper[9], higher loss per active volume as observed in D-I and D-II can result in serious thermal implications, which may need to be carefully addressed.

The PMSG is designed with rare earth PMs, which should result in a trade-off between the active mass and total costs. Consequently, the cost analyses of the generators are contrasted, as shown in Table 3. It is observed that although the total active mass of the PMSG is smaller than the WF- FSM designs, its total cost is about twice as much. The reverse is the case for the WF-FSM designs, which shows their total masses to be much higher, yet the cost of material is significantly reduced because they are rare earth-free.

It should be mentioned that although the comparison between the direct-drive PMSG and the geared WF-FSM designs is not precisely comfortable. This is because of their different drivetrain configurations. Yet, it gives insight to the fact that the avoidance of rare-earth PMs may positively impact on the latter's total cost of materials.

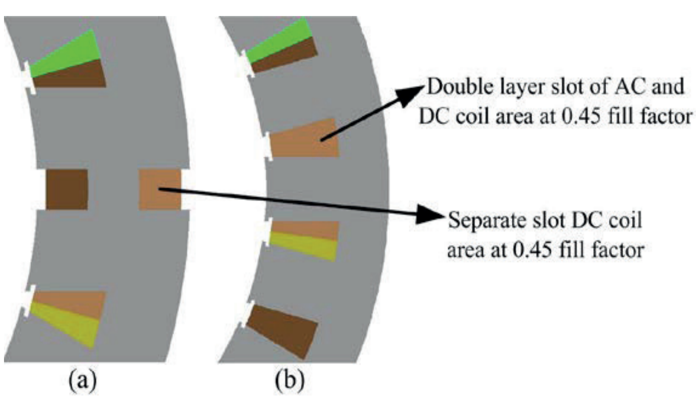

Figure 4: Depiction of the slot filling areas in 2D FEA modelling: (a) D-I, and (b) D-II.

3D FEA VALIDATION AND EXPERIMENTAL PROTOTYPE

This section presents the 3D FEA validation of the studied WF-FSMs, as well as preliminary results achieved from an existing 10 kW prototype of D-I designed, built and tested as a wind generator in the Electrical Machines Laboratory of Stellenbosch University, South Africa, in 2017, for the first time[15].

3D FEA VALIDATION

In Figure 5, the flux density plots of the 300 kW WF- FSMs evaluated in 3D FEA as quarter-symmetrical models are presented. The peak density flux in the iron cores reaches 2.3 T in trace proportions in regions close to the airgap, at rated conditions. Table 4 is then introduced by way of comparing the 2D and 3D FEA evaluations to account for the end fully-winding effects. It is clear enough that the end-winding effects were seriously underestimated in D-II, as witnessed by the significant increase in the total copper losses. This considerable drop has to be implicated in the discrepancy observed in the average torque, torque density and efficiency. The highlight

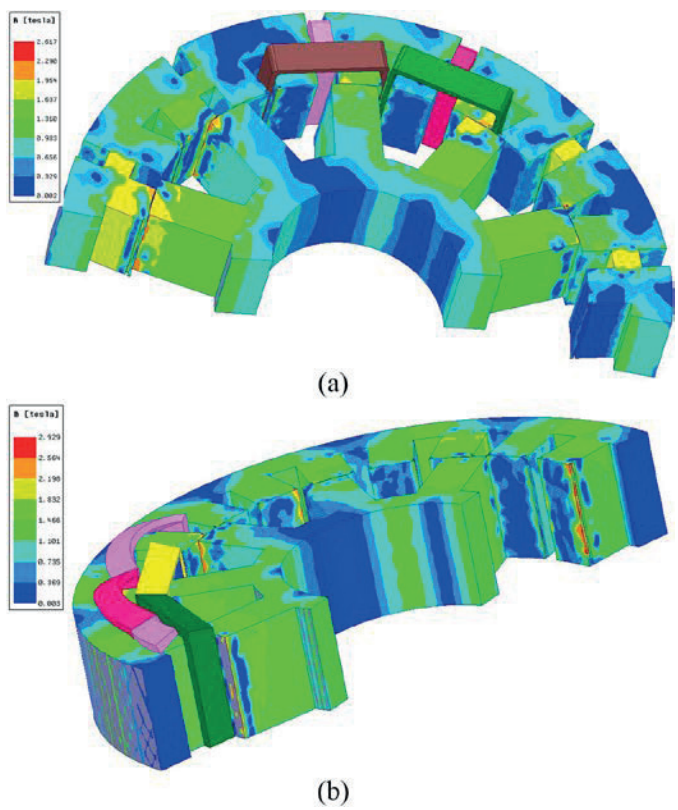

Figure 5: 3D FEA predicted flux density contour plots of the studied 300 kW WF-FSMs at rated conditions: (a) D-I, and (b) D-II.

Figure 6: Manufacturing process of a 10 kW WF-FSM wind generator prototype[15].

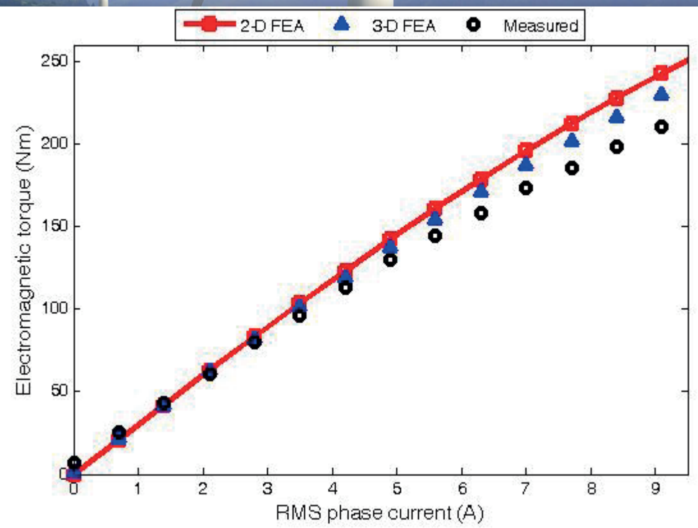

Figure 7: Measured electromagnetic torque under varying load current[11].

of end-winding effects is the reversal of the P_{loss}/V_{act} index between the machines, which suggests in reality that it may be worse for D-II than D-I. Also, a vast difference in the torque ripple of D-II is observed. The trend, which appeared to be steadfast in 2D and 3D FEA, is that the torque density of the D-II is slightly maintained above that of D-I, as well as attainment of unitary power factor in the former.

EXPERIMENTAL PROTOTYPE AND TESTS

The main handout from the experimental demonstration is that the manufacturing is 100% South African, without the need for the importation of any of the resource components used in the fabrication process. In Figure 6, the highlights of the manufacturing process are photographically profiled. Figure 7 is used to gauge some of the measured results with those predicted initially at the design stage. At higher loading, it appears the effect of saturation becomes daring. Other than that, a good agreement is indicated. The level of agreement achieved through the experimental testing of the 10 kW prototype yields some promise as to the feasibility of furthering the power levels to the proposed 300 kW wind generator concepts for South Africa's wind power industry, as already being initiated in this study.

CONCLUSIONS

In this paper, an optimal design comparison has been initiated for two wound-field flux switching machine variants. It is profiled as D-I and D-II, at 300 kW power ratings, to demonstrate the industrial relevance of rare earth-free wind generators to the booming South Africa wind power industry. In 2D finite element analyses (FEA), D-II shows better performance credentials in response to the specified design constraints, but with a significant discrepancy in the specific direct current copper losses observed due to unfair approximations of the slot filling factors. However, after undertaking 3D FEA, the results show that the end-winding effects of D-II have been seriously underrated, of which among other things, the P_{loss}/V_{act} index increases by 15% compared to D-I.

However, the torque density and power factor of D-II remains steadfastly higher than D-I, even in 3D FEA. At the time of writing, a locally manufactured 10 kW laboratory prototype of D-I existed, ensuring that some experimental validation is provided. In conclusion, the study uncovers some degree of design feasibility with perceived economic benefits of the proposed wind generators for South Africa's wind power industry. wn

Table 4: Comparison between 2D and 3D FEA performance data of 300 kW wind generators.

	$\Delta\tau_L$ (%)		P_{cu} (kW		P_{core} (kW		T_r (kNm)		η (%)		P_{loss}/V_{act} (kW/m^3)		T_r/V_{act} (kNm/m^3)		PF -	
	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D
D-I	8.76	8.85	15.63	15.60	3.16	3.56	9.52	9.03	94.15	93.67	41.38	42.19	20.86	19.88	0.79	0.65
D-II	5.56	17.96	10.52	16.08	2.32	2.09	9.43	8.24	95.91	93.44	34.29	48.53	24.79	22.00	0.98	1.00

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Lightning and surge protection for electromobility

DEHN Africa provides lightning and surge protection for electric vehicle charging stations

Because most electric vehicle charging stations are generally positioned outside, they are more vulnerable to the effects of direct lightning strikes, as well as the possibility of resultant surges.

In mid-2019, there were an estimated one thousand electric vehicles (EV) registered in South Africa[1]. In October of last year, the practicality of the local charging network was tested when seven EVs went on a road trip from Pretoria to Cape Town[2].

Generation.e organised the road trip – an events company with a mission to accelerate EV adoption - in partnership with the Gauteng Provincial Government, the African Alliance for Energy Productivity and the Department of Transport.

As at early 2020, there are reported to be 132 designated charging stations throughout South Africa[3], with brands such as Renault, Mini Cooper, Porsche and Audi preparing to add either fully electric or hybrid vehicles in 2020[4] to the existing offerings from Nissan (the Nissan Leaf), BMW (i3) and Jaguar(I-PACE). Most car experts agree that the adoption of electric cars is bound to increase in the next few years as more public charging stations become available throughout the country.

Read more on the solutions offered from DEHN Africa in the below white paper on lightning and surge protection for EV charging stations.

DANGER DURING THUNDERSTORMS

Several billion flashes of lightning come down in the world every year. In Germany alone, an average of 1.5 million lightning events are counted each year, and the tendency is rising. If lightning strikes nearby, buildings and the infrastructure often suffer damage: lightning strikes can cause fires and surge damage to electrical devices and systems. The latter may occur even if the actual strike was up to 2 km

away. Besides, switching electrical power, e.g. on the charging post, and switching operations in transformer stations generate switching overvoltages which can also have adverse effects. It frequently only takes a small amount of energy to cause significant damage.

DAMAGE CAUSED DURING CHARGING

Constant availability of electrical power is a decisive factor for the charging process. The fact that charging stations is primarily erected outside means that they are especially susceptible to the effects of lightning discharge and the resulting surges which might exceed the dielectric strength of the electrical components within the charging post many times over. Furthermore, voltage peaks in the power grid from, e.g. switching operations or earth faults and short-circuits, should be regarded as a possible threat. The consequences are defective electronic components and a charging post which is out of order.

Should the surge occur during the charging process itself, it can even damage the actual vehicle (e.g. the charge controller or battery). It is therefore advisable to consider a reliable lightning and surge protection concept to avoid such financially damaging consequences and minimise repairs and maintenance.

WHAT HAPPENS IF LIGHTNING STRIKES WHEN CHARGING?

In case of a direct lightning strike, e.g. in a street lamp, a partial lightning current can flow to the charging post. This can be conducted directly into the vehicle via the attached charging cable where it may destroy the charging electronics or even the battery. If a surge protective device has been installed, the lightning current and the overvoltage is discharged directly via the protective device and the charging equipment, and the vehicle remains intact (Figure 1).

WHAT DO THE STANDARDS HAVE TO SAY?

Publication VdS 3471, issued by the VdS (German insurer for damage prevention), on 'Charging stations for electric vehicles' states on the topic of surge protection that, according to DIN VDE 0100-443, the evaluation of whether additional surge protective measures are necessary, depends on the overvoltage category stated by the manufacturer.

Standards in the series DIN VDE 0100 are installation standards and therefore apply to fixed installations. Charging posts which

Lightning Protection for electromobility

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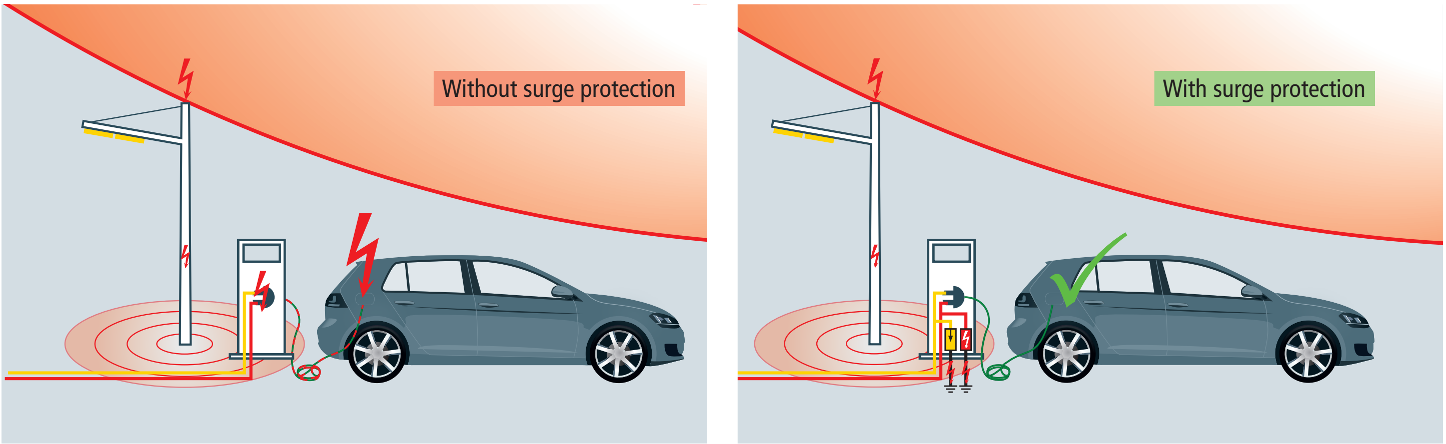


Figure 1 - Lightning and surge coupling when charging

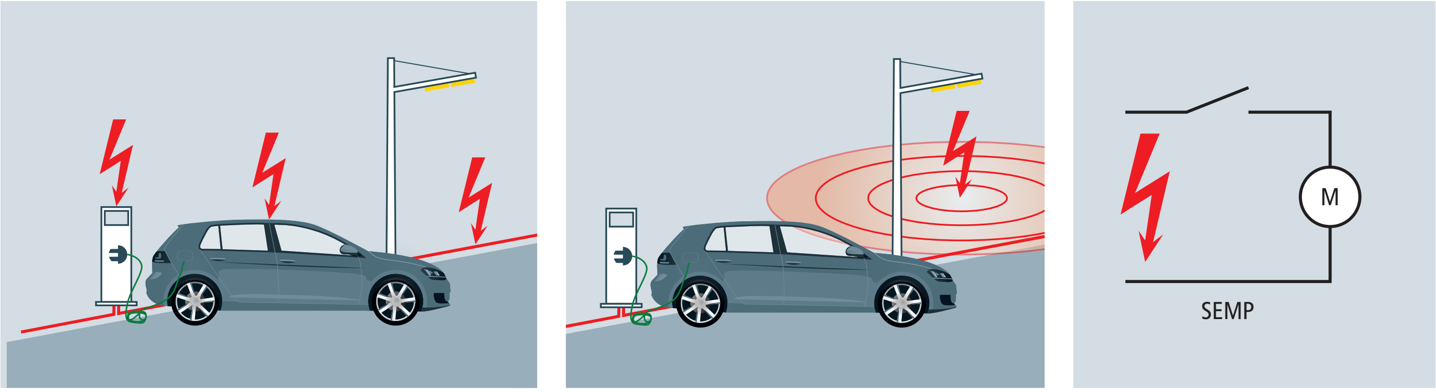


Figure 2 - Causes of overvoltage

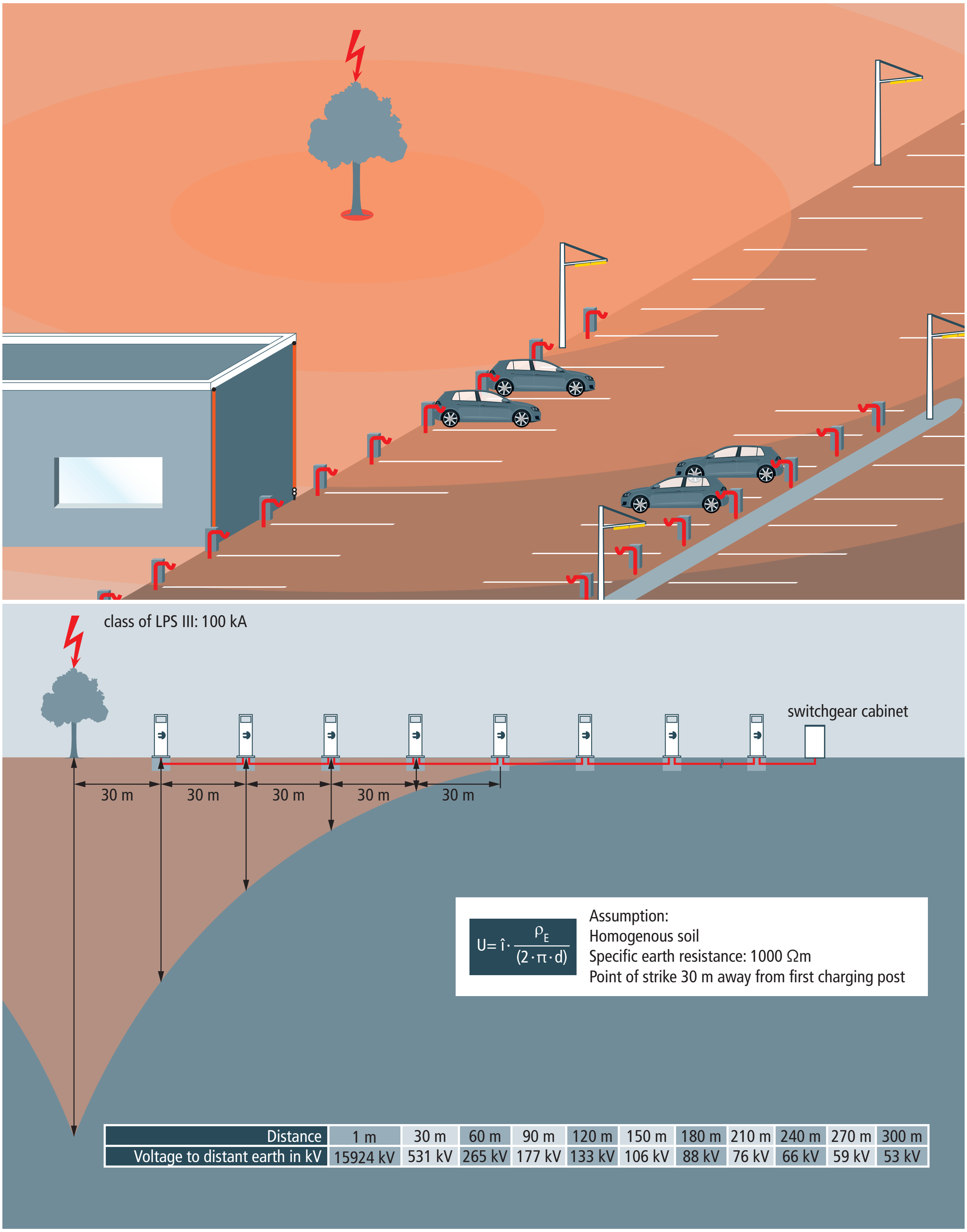
are not portable and are connected via fixed wiring fall under the scope of DIN VDE 0100.

DIN VDE 0100-443:2016-10 deals with the protection of electrical installations against transient overvoltages of atmospheric origin. These are transmitted through the power grid, including direct lightning strikes in power lines and transient overvoltages due to switching operations. It explains whether surge protective measures are necessary, assesses the risk of the location, defines overvoltage categories and the correspondingly required rated impulse withstand voltage level for the equipment and defines whether additional surge protective devices are necessary. Furthermore, it expands on the required availability of the system. If the risk of direct lightning strikes needs to be considered, lightning protection standard DIN EN 62305 (VDE 0185-305) should also be applied.

The technical guidance document *"Charging infrastructure/ electromobility"* by the DKE / AK EMOBILITY.60 (a working group of the German Commission for electrotechnology) refers that, in the interest of preventing damage and injury, these standards should be assessed and considered. Should lightning and surge protective measures be applied in compliance with DIN VDE 0100-443 and EN 62305, these should be installed according to DIN VDE 0100-534.

CAUSES OF TRANSIENT OVERVOLTAGE

A direct strike to the charging post or the supply line produces a lightning current which is simulated under test conditions with the impulse shape 10/350 µs. Distant lightning strikes or so-called indirect lightning strikes lead to conducted partial lightning currents (impulse shape 10/350 µs) in the supply lines or also to inductive/



Distance	1 m	30 m	60 m	90 m	120 m	150 m	180 m	210 m	240 m	270 m	300 m
Voltage to distant earth in kV	15924 kV	531 kV	265 kV	177 kV	133 kV	106 kV	88 kV	76 kV	66 kV	59 kV	53 kV

Figure 3 - Potential gradient area for a lightning strike in the immediate vicinity of a charging station

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capacitive coupling (impulse shape 8/20 µs) in the charging stations themselves. Besides, overvoltage can be caused by switching operations, earth faults and short circuits or when fuses trip (SEMP – switching electromagnetic pulse) (Figure 2 and 3).

Surge protection should be selected according to DIN VDE 0100-534 depending on the location of the charging post or wall box (Figure 4). If the charging post or its wiring is in zone 0A, both galvanic coupling and coupling of partial lightning currents must be expected in case of a nearby or distant lightning strike.

Type 1 + 2 + 3 combined arresters, e.g. DEHNshield, should be installed in the charging posts to control these interference impulses. If the charging posts or wall boxes and their wiring are in zone 0B, i.e. in an area protected against strikes, one only needs to reckon with inductive and capacitive coupling from the lightning discharge. In this case, type 2 surge arresters like, for example, DEHNguard suffice. If it is not possible to reliably assess the potential threat, installing the compact and space-saving type 1 + 2 + 3 combined arrester DEHNshield is generally the best option. DEHNshield is based on spark-gap technology, has VDE and UL certification, is maintenance-free, offers protection against both the direct and indirect effects of lightning and is, therefore, a flexible and universal solution. As this arrester is purely based on spark gap technology, the wave breaker function is assured.

This has the effect of reducing the energy of the lightning impulse current to such an extent that even the most sensitive electronics installed downstream remain intact. This constitutes real protection of terminal devices!

SELECTION OF SURGE PROTECTIVE DEVICES

When selecting suitable lightning and surge protective devices, it is not only essential to know about the installation location but also about the local system configuration, system voltage and nominal voltage of the charging facility. A possible selection is shown in table 1. wn

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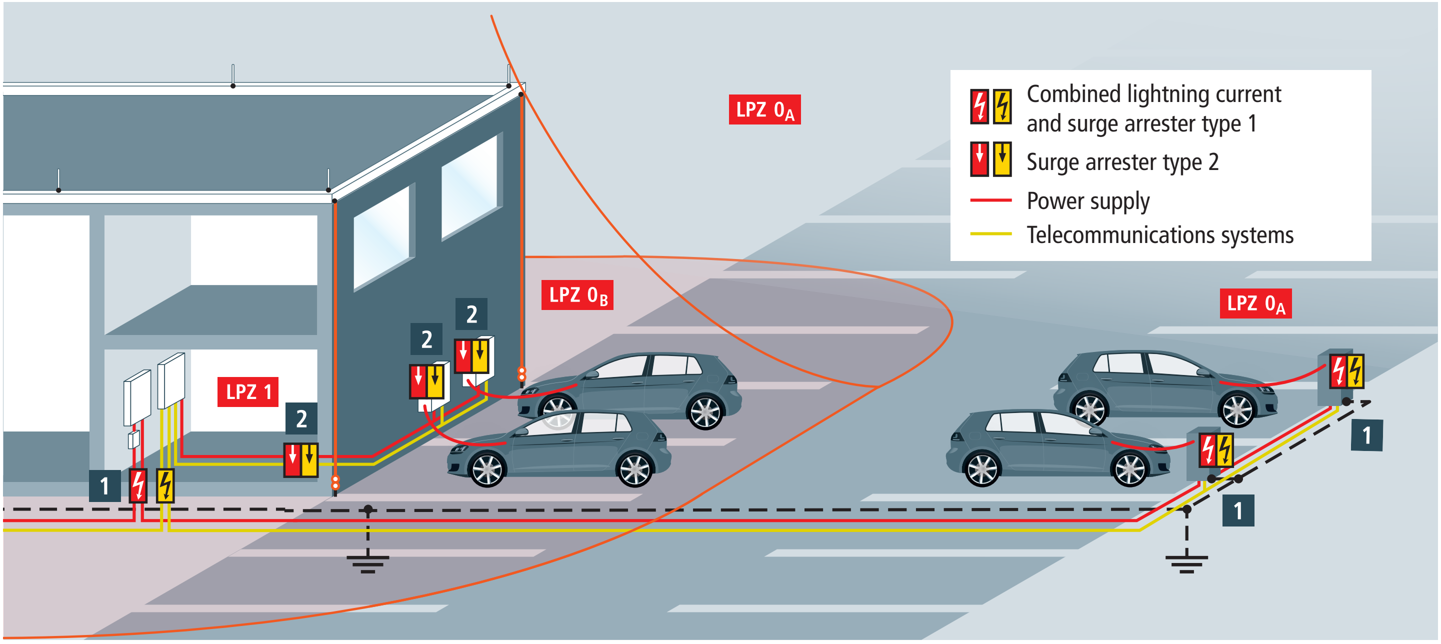


Figure 4 - Application of lightning and surge protective devices depending on location

No.			Type	Part No.	Other
Protection against the direct and indirect effects of lightning					
1	Combined arrester type 1 + 2 + 3 230/400V (50/60 Hz)	DEHNshield	DSH TT 255 FM	941 315	TT and TN system, DIN rail mounting
		DEHNshield ZP	DSH ZP TT 255	900 397	TT and TN system, 40 mm busbar mounting
	Data and communication lines*	BLITZDUCTOR XT	BXT ML4 BD HF 5 + BXT BAS	920 371 + 920 300	Module and base part, e.g. for RS485
Protection against the indirect effects of lightning					
2	Combined arrester type 2 + 3	DEHNguard modular	DG M TT 275 FM	952 315	TT and TN system, DIN rail mounting
	d.c. applications	DEHNguard SE DC	DG SE DC 900 FM	972 145	e.g. highest continuous operating voltage d.c. 900 V
	Data and communication lines*	BLITZDUCTOR SP	BSP M4 BD HF 5 + BXT BAS	926 371 + 920 300	Module and base part, e.g. for RS485
		DEHNpatch	DPA M CLE RJ45B 48	929 121	e.g. Power over Ethernet
* Selection depending on the interface					

Table 1 - Selection aid for protecting electromobility – charging infrastructure (Figure 4)

January in History

January is the first month of the year in the Julian and Gregorian calendars and the first of seven months to have a length of 31 days. The first day of the month is known as New Year's Day.

COMPILED BY I
JANE BUISSON-STREET
FSAIEE I PMIITPSA I FMIITSPA

1 JANUARY

2019 The long-awaited national minimum wage came into effect in South Africa.

2 JANUARY

2004 The NASA spacecraft Stardust successfully flew past Comet Wild 2, collecting samples to be returned to Earth. The primary mission was successfully completed on 15 January 2006, when the sample return capsule returned to Earth.

3 JANUARY

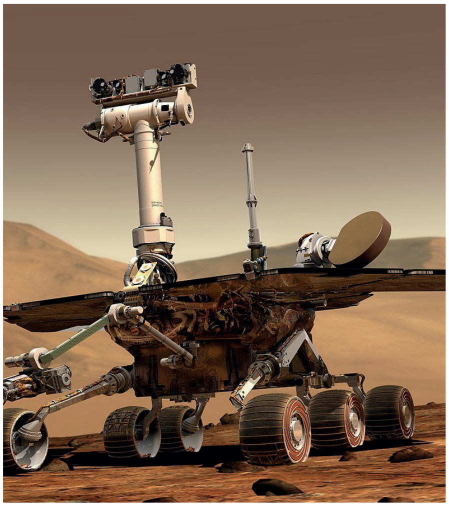
1977 Less than one year after its founding, the world's first personal computer company, Apple Computer, Inc. was incorporated. The original Apple Computer, Inc. logo was the "Rainbow Apple Logo" used through to 1999.

4 JANUARY

2004 Spirit, a NASA Mars Rover, landed successfully on Mars. Nearly 6 years after the original mission limit, Spirit had covered a total distance of 7.73 km but its wheels became trapped in sand. The last communication received from the rover was on March 22, 2010, and NASA ceased attempts to re-establish communication on May 25 of that year.

5 JANUARY

1984 Richard Stallman began developing the software for the GNU operating system, intended to be a free UNIX-like OS. The goal was to bring a wholly free software operating system into existence. Stallman wanted computer users to be free to study the source code of the software they use, share software with other people, modify the behaviour of software, and publish their own modified versions of the software. This philosophy was later published as the GNU Manifesto in March 1985.



6 JANUARY

1984 Hitachi announced that they had developed the first memory chip capable of holding 1 MB of data!

7 JANUARY

1990 The Leaning Tower of Pisa was closed to the public for the first time in 800 years because it was leaning too much..

8 JANUARY

871 Battle of Ashdown: Ethelred I of Wessex and his brother Alfred the Great beat invading Danish army.

9 JANUARY

1793 1st hot-air balloon flight in the US lifts off in Philadelphia, piloted by Jean Pierre Blanchard.

10 JANUARY

1863 The first underground railway opens in London.

11 JANUARY

1838 The first public demonstration of telegraph messages sent using dots and dashes at Speedwell Ironworks in Morristown, New Jersey by Samuel Morse and Alfred Vail.

12 JANUARY

1948 Mahatma Gandhi begins his final fast.

13 JANUARY

1942 Wartime material shortages forced manufacturers to become very creative so Henry Ford patented a Soybean car (a plastic car), which was 30% lighter than a regular car. Henry Ford came up with a unique tubular steel framework which he could bolt his plastic panels on. It is believed the plastic was made from Soybean, so that car was also called Soybean car.

14 JANUARY

1878 Alexander Graham Bell demonstrated the telephone for the first time to Queen Victoria at her rural retreat at Osborne House in East Cowes. He made the UK's first publicly-witnessed long distance calls, calling Cowes, Southampton and London. When the Queen saw his telephone, she was much impressed, and ordered a private line to be laid between Osborne House, on the Isle of Wight, and Buckingham Palace.

15 JANUARY

1797 The top hat was first worn in England by James Heatherington, a Strand haberdasher in London, England. An issue of the Times of that period records that when he left his shop with his extraordinary headwear, a crowd of onlookers assembled, which degenerated into a shoving match. Consequently, Heatherington was summoned to appear in court before the Lord Mayor and fined £50 for going about in a manner "calculated to frighten timid people.

16 JANUARY

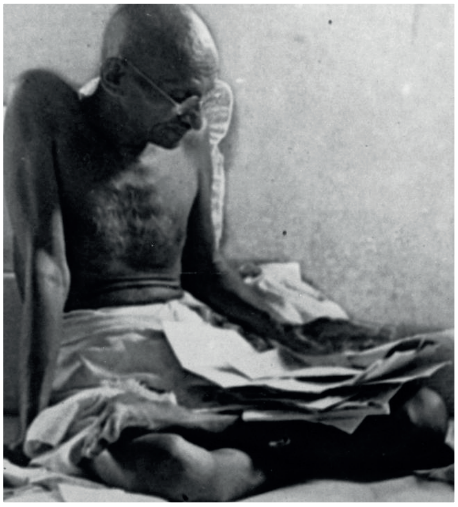
1980 Scientists in Boston, USA produced interferon, a natural virus-fighting substance through genetic engineering.

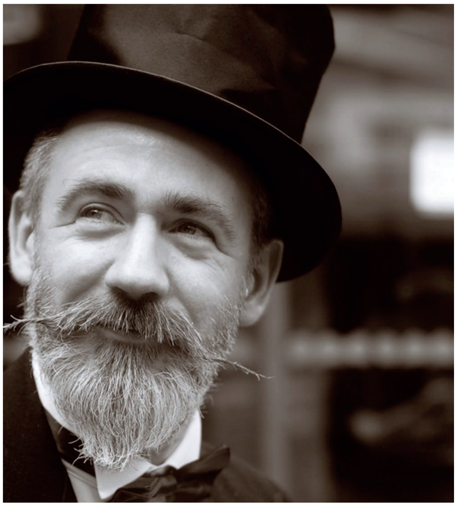
17 JANUARY

1874 – Twins Chang and Eng Bunker died. They were Siamese-born American twins joined at the chest and are the source of the term "Siamese Twins." They toured Europe and the U.S., eventually settling in North Carolina where they married two sisters, who bore them 22 children. "Chang" and "Eng" is Thai for "Left" and "Right."

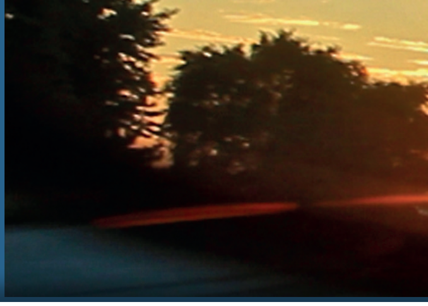
18 JANUARY

1919 This was the first day of The Paris Peace Conference, also known as the Versailles Peace Conference, of the victorious Allied Powers following the end of World War I to set the peace terms for the defeated Central Powers. Two of the outcomes of this Conference





January in History



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was the creation of the League of Nations and the Treaty of Versailles.

19 JANUARY

1999 Research In Motion (RIM) introduced the BlackBerry. The original BlackBerry devices were not phones, but instead were the first mobile devices that could do real-time e-mail. They looked like big pagers. Apparently the name "BlackBerry" came from the similarity that the buttons on the original device had to the surface of a blackberry fruit.

20 JANUARY

1970 "The Super Fight", a computerized, fictional boxing match between Muhammad Ali and Rocky Marciano "took place". The fictional fight was created by filming Ali and Marciano acting out every possible scenario in a fight and the result was then determined using probability formulas entered into a computer.

21 JANUARY

2000 The domain name twitter.com was registered. However, it wasn't until 2006 that the domain was purchased by Twitter, Inc. and took the form known today.

22 JANUARY

1968 The first unmanned lunar module lifted off in Apollo 5 (also known as AS-204).

23 JANUARY

1996 The first version of the Java programming language was released (confusing many coffee drinkers). The ability of Java to "write once, run anywhere" made it ideal for Internet-based applications. As the popularity of the Internet soared, so did the usage of Java.

24 JANUARY

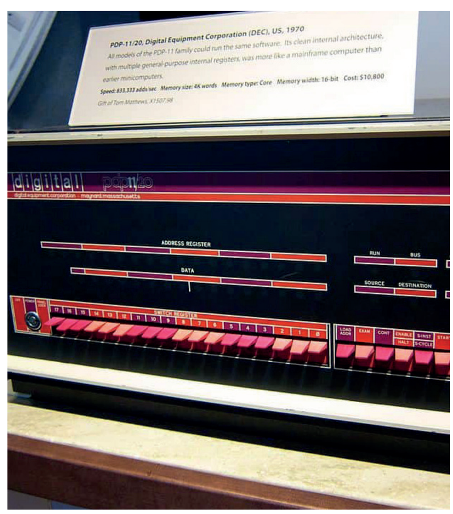
1950 The patent of one of the most used piece of equipment in many people's kitchens, the microwave, was issued to Percy LeBaron Spencer under the title "Method of Treating Foodstuffs." Five years earlier, Spencer accidentally discovered that microwave energy could heat food when a chocolate bar in his pocket melted while he was experimenting with a microwave tube. Microwave tubes were originally designed for RADAR systems.

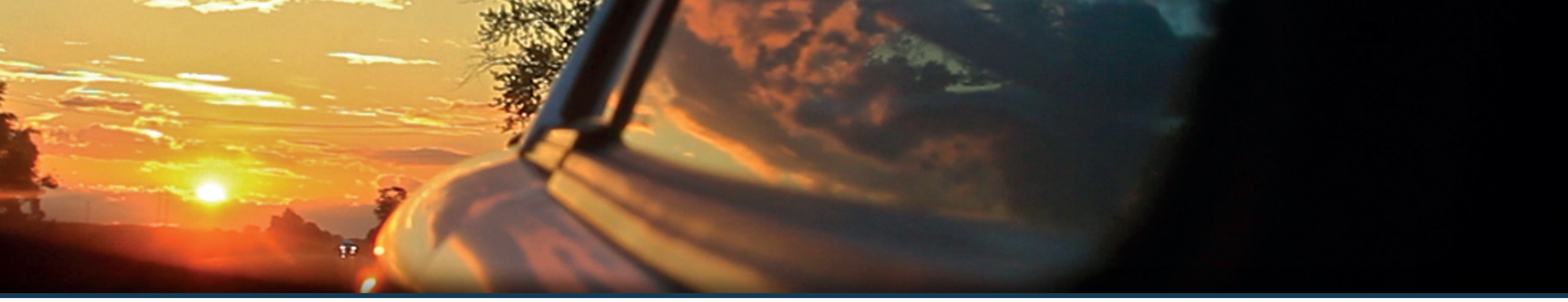
25 JANUARY

1905 At the Premier Mine in Pretoria, South Africa, a 3,106-carat diamond was discovered during a routine inspection by the mine's superintendent. Weighing 603 grams, and christened the "Cullinan," it was the largest diamond ever found.

26 JANUARY

1998 Compaq Computer purchased Digital Equipment Corporation (DEC) for $9.6 billion. DEC was a pioneering company in the early history of computers from the 1960s to the 1980s. Unfortunately, as was seen with many companies, they were slow to recognize the





rise of the PC which ultimately led to the sell-off of all the company's business units, cumulating with the final sale to Compaq. Compaq itself was eventually merged with HP.

27 JANUARY

1967 Astronauts Gus Grissom, Edward White and Roger Chaffee were killed in a fire during a test of their spacecraft at the Kennedy Space Centre. After the fire, the spacecraft and planned launch which never took place was posthumously named Apollo 1, in honour of the astronauts.

28 JANUARY

1999 Yahoo! bought GeoCities for $3.65 billion USD. GeoCities was an early web hosting service that start in 1994. As a testament to its popularity, there were at least 38 million pages remaining on GeoCities when Yahoo! shut it down in 2009.

29 JANUARY

1988 The computer game Tetris made its first appearance in the United States as a PC game. The company that released the game was Spectrum Holobyte, which had dubious licensing rights to the game. When companies became interested in licensing Tetris for other platforms besides the PC, a series of events kicked off a long legal battle, in which the big winner was eventually Nintendo, who used the game Tetris to drive sales of its new Game Boy platform.

30 JANUARY

1982 Richard Skrenta (a 15-year old school boy) wrote the first PC virus code, which was 400 lines long and disguised as an Apple II boot program called "Elk Cloner".

Elk Cloner was spread by infecting the Apple DOS 3.3 operating system using a technique now known as a boot sector virus. It was attached to a game which was then set to play. The 50th time the game was started, the virus was released, but instead of playing the game, it would change to a blank screen that displayed a poem about the virus.

Elk Cloner: The program with a personality
It will get on all your disks
It will infiltrate your chips
Yes, it's Cloner!

It will stick to you like glue
It will modify RAM too

Send in the Cloner!

Twenty-five years later, in 2007, Skrenta called it "some dumb little practical joke."

31 JANUARY

1990 The first McDonald's was opened in Russia, in the city of Moscow. The restaurant served at least 30,000 people during its first day. wn

yahoo!

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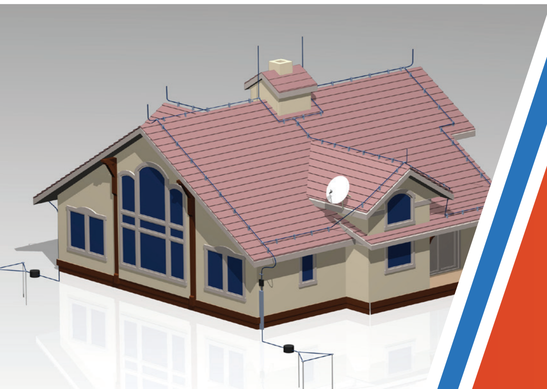

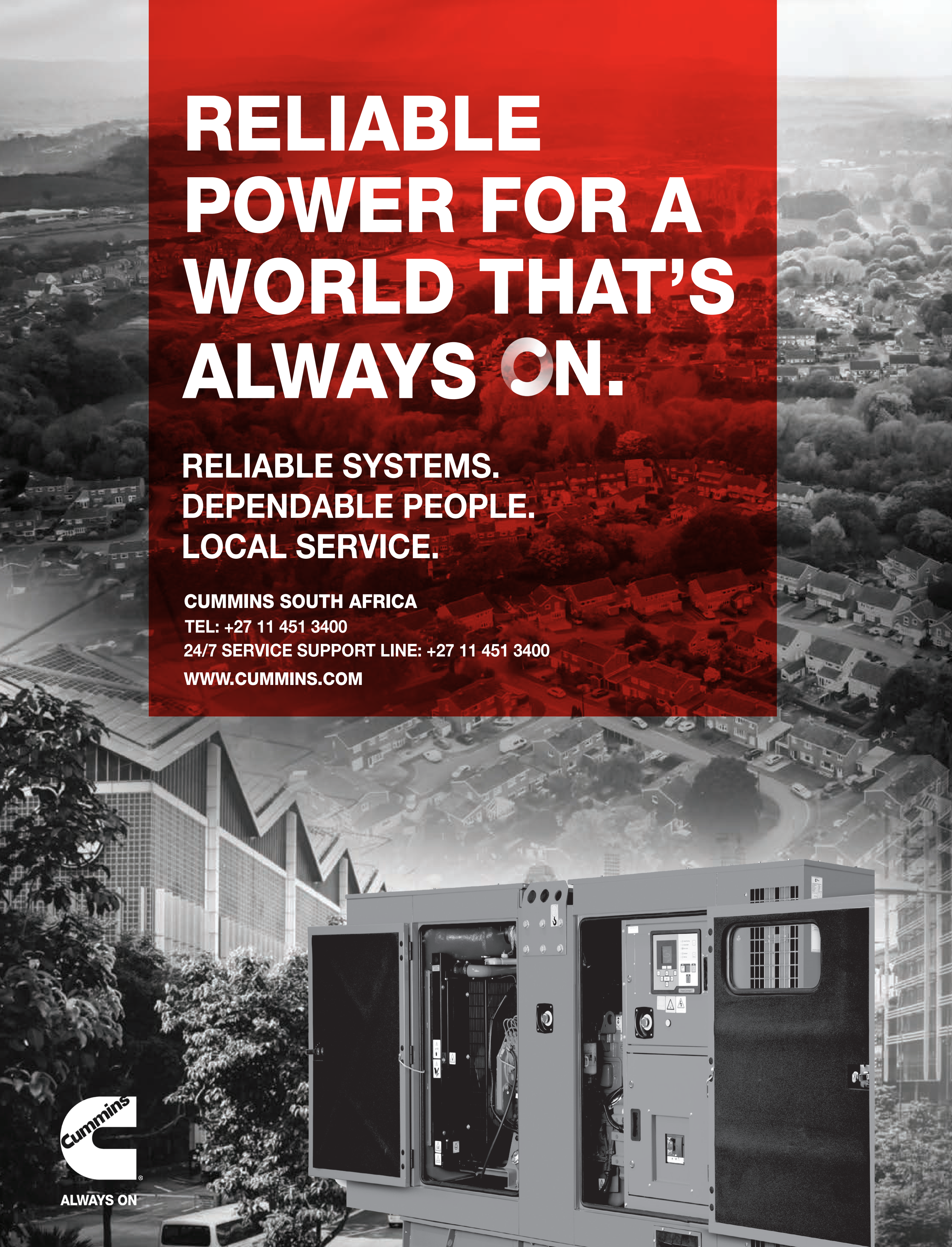
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