Energy Efficiency Made Simple Vol IV

Energy and enviroFiciency 2015

Today, tomorrow

Foreword

By Ian Jandrell

Perspective on Energy + enviroFiciency: Today, tomorrow

Prior to the turn of the century, few people could envisage any possible environmental effect of using less energy. Energy efficiency was neither a sexy topic nor a real concern and therefore barely worth consideration. Electricity + Control did make a case for energy efficiency – but it was seen to be on the fringe of the real value of industry, which was to 'produce better products at better prices, and optimise the bottom line'.

Because it now costs so much more, energy has a major impact on that bottom line. It is the bottom line that has forced us to recognise the importance of energy efficiency, energy management and the fact that every step we take to optimise a process makes it more effective and more profitable.

We have also come to realise that our planet needs to be nurtured; that it needs to be cared for; and that a sustainable future depends on how we manage this special resource now – not at some time in the future.

So the need to save energy, and find sustainable and less damaging ways of producing it, began to come together at the start of this century. Although some consider it a bit late, it is evident that we are on the road, moving in a better direction.

All this makes me reflect on the role of the engineer. I am convinced that engineering is one of the oldest (possibly not the first) real endeavours (or professions) of human kind. At its core, engineering is about understanding the world in which we live, the laws of nature and the physical world – and then harnessing these to improve our lot.

I imagine that one of the first things we did was figure out how to keep crops irrigated, how to prepare food, and how to deal with the need for shelter. These were early takes on engineering and were about trying to make our communities safer and more sustainable.

As time passed and the world we lived in advanced, we began to formalise the means to take advantage of our understanding of the world. Concepts like the tendency of water to flow downhill, of fire to cook food, of certain plants to heal – and so forth – took root.

As human beings, we are able to communicate and record - to tell stories – and this is what we did. We developed the ability to teach youngsters what we knew. We no longer had to rely on learning by experience. We could teach and develop the skills and competencies needed to make the world work.

We discovered metals, and began to learn of their properties. The mining industry began.

The volume of knowledge became too big. As our understanding of the world became even more profound we simply had to formalise the training – until we arrived where we are today: Members of the engineering team end up at educational institutions that train them in their disciplines.

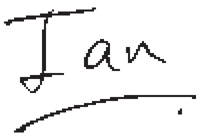
Throughout the ages, the fundamental basis of everything we have done, do and attempt to do, is make the world a better place in which to live.

Over time, we may have drifted off that trajectory (maybe it is just me), but it strikes me that the urgency around the energy question is forcing us to revisit our primary purpose: to make it better.

This handbook takes you on a journey through some of that thinking – looking at the basics, the existing and the developed – and asking questions about what the future may be like. Do we take too much for granted?

At the end of the day, in as much as we need to change or rethink the technologies we use, so too as people we may need to rethink what we do and how we do it.

Enjoy this overview of how our thinking has had to change and the opportunities that exist.



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contents

Energy + enviroFiciency

contents

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Published by: **Crown Publications cc.** • Cnr Theunis and Sovereign Sts, Bedford Gardens, PO Box 140, Bedfordview 2008
• Tel: (011) 622-4770 • Fax: (011) 615-6108 • e-mail: ec@crown.co.za; admin@crown.co.za • Website: www.crown.co.za • Printed by: Tandym Print

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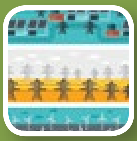

Chapter 1

Energy in Southern Africa

There is a wonderful map of Africa that shows how you can fit the countries of the world into the area of Africa. It is a humbling image – especially if you are not African. Energy is the key to continental development. The opportunities are enormous.

1

Energy in sub-Saharan Africa
Today and tomorrow

P Lloyd, Energy Institute, Cape Peninsula University of Technology

Sub-Saharan Africa is currently developing strongly, albeit from a very low base. One of the essential elements for development is, however, not receiving the attention it needs, namely energy and particularly electrical energy. The Republic of South Africa is struggling to meet its own needs, yet it has about 40 times as much per capita as the average other sub-Saharan nations. This provides us with a measure of the gap that is to be closed if the region is to have a chance of achieving its potential in the foreseeable future.

Energy and wealth creation are inextricably linked. The availability of energy sets man free from the physical toil required to win the basic necessities of life – food, water and housing. Freed from physical toil, we can live longer and healthier lives. We can start to control population. Without energy, we need our children to care for us because we are aged before we are 45 and dead before we are 55. With energy, we can gather in cities and be surrounded by the gifts of modern life, including living long enough to see our grandchildren become adults. *Figure 1* shows how directly electrical consumption and wealth are related.

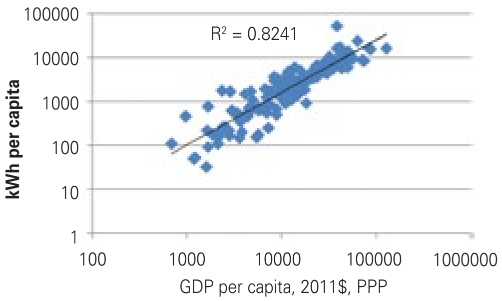

Figure 1: The relation between wealth, as measured by GDP per capita, and electrical consumption [1].

As your income approaches $100 000 per capita (in 2011 $), the chances are that you will use over 10 000 kWh per year. At under $10 000 per capita, you will be lucky to have more than 500 kWh per year. It is not clear whether wealth drives consumption or consumption drives wealth – but what we do know is that you must have energy. Energy is absolutely necessary for development. However, it is not a sufficient condition – there are energy-rich nations whose socio-economic culture holds back their economic development.

It seems likely that over the next 35 years, sub-Saharan Africa's population will increase dramatically; that we will see cities springing up across our continent; and that we will need to generate power on a scale presently undreamt of. So let us reflect on where we are, where we might be going, and what we will have to do to get there.

Where we are

Today, the energy scene of sub-Saharan Africa is dominated by one player, South Africa. Its citizens enjoy an average of nearly 6 000 kWh per capita per annum. Interestingly, the per capita consumption has been constant for 25 years, so all growth in generation has been devoted to the well-being of its people, not to economic growth.

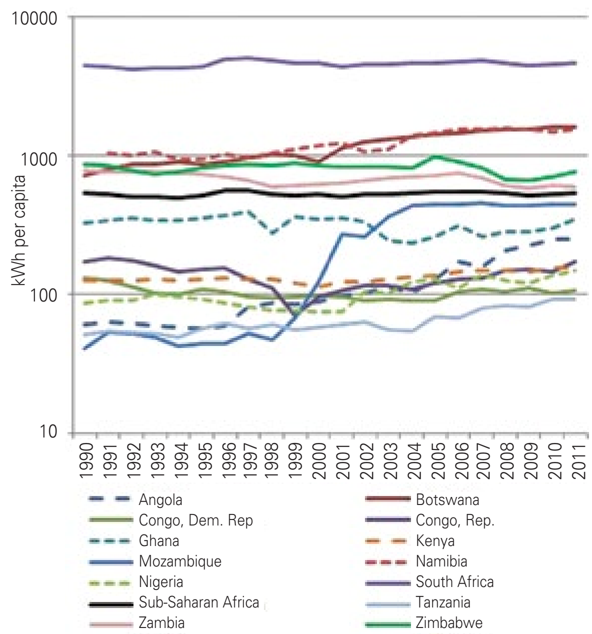

Figure 2: Per-capita consumption of power in sub-Saharan Africa – 1990 – 2012 [1].

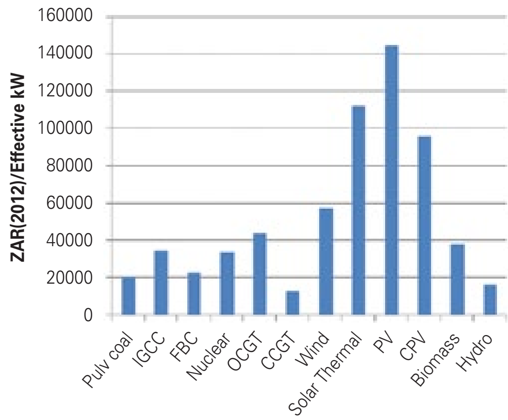

Figure 3: Effective overnight costs of various generating technologies [2].

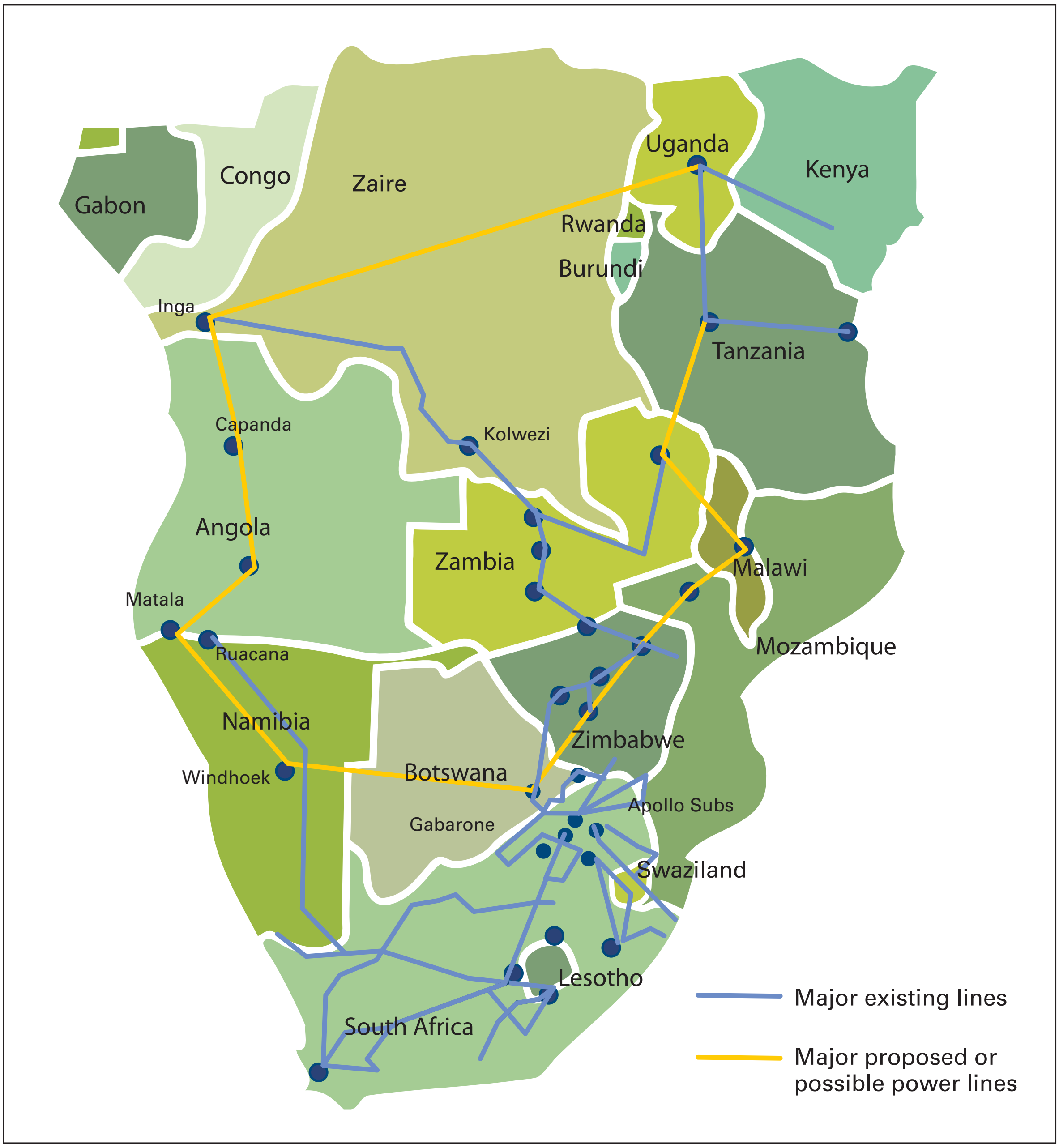

Figure 4: Power transmission in Southern Africa.

Botswana and Namibia have grown their output in recent years, and today their citizens enjoy nearly 2 000 kWh/annum. In contrast, the relative supply in Zambia and Zimbabwe has dropped, although it is still above the average supply in the region. All other nations have less than the regional average; the only remarkable feature is the surge in the power available to Mozambicans after the mid-1990s. Angola, Kenya and Nigeria have managed to grow their supply slightly, but they are still, in world terms, extremely short of power. Globally, the average citizen enjoys the benefits of about 3 000 kWh per annum. Only South Africa is above the global average. It seems a reasonable target that the region should strive to have as much power as the world average. Let us examine what that would require.

Where we want to go

Sub-Saharan Africa used about 440 TWh of electricity in 2012, of which South Africa used almost exactly half – the rest of the region used 224 TWh [1].

If we disregard South Africa, and calculate the needs of the rest of the population of the region, with each citizen receiving 3 000 kWh per annum, then the region would need some 2 620 TWh. In other words, in 2012 the region had a shortfall, relative to the world average, of some 2 400 TWh, about ten times South Africa's present consumption.

At an 85% load factor, that means about 295 MW of base load generation. This is the minimum generating capacity that needs to be installed just to raise the electricity supply of the region to world levels. An average load factor closer to 60% is more normal, which would indicate the need for about 400 GW of installed capacity.

Generating capacity is not cheap. *Figure 3* shows the overnight capital costs for new generating capacity for various technologies [1], where the costs have been corrected for load factor – so, for instance, nuclear power typically supplies base load at 90% load factor, and the effective cost shown in *Figure 3* is the overnight cost/90%.

Clearly, Combined Cycle Gas Turbines (CCGTs) and hydro power are the low cost options and should be pursued wherever these resources are available. Coal is the next cheapest option, and significant unutilised reserves are known in the region. Nuclear and biomass are the remaining technologies costing less than ZAR40 000 per effective kW, and both present real challenges, so should only be considered as last resorts. None of the 'new renewables' (wind and solar) look promising in an environment where capital is a major constraint.

If we assume ZAR20 000 per effective kW installed, then 400 GW of generating capacity will require a total of ZAR8 trillion, or about US$800 billion. This is a huge sum in sub-Saharan terms, and even spread over, say, 15 years, it would require over $50 billion a year to achieve. Is it affordable?

How can we get there?

There are huge demands for infrastructure in sub-Saharan Africa. It is therefore a challenge to find a reason for giving power supply any priority over other infrastructural demands. Fortunately, there is now a value for power. It has been possible to assess the cost to the South African economy of the collapse of its network in 2008. Each kWh that was not provided cost the economy ZAR75 in 2010 terms [1]. A shortfall of 2 400 TWh in the sub-Saharan African region outside South Africa could therefore be costing the economies in the order of ZAR200 trillion, or $20 trillion per annum. Spending $50 billion to make $20 trillion seem like a real opportunity.

However, we have to remember that having adequate energy is only a necessary condition for growth. Actual growth will occur when there has been sufficient socio-economic development to be able to utilise the power. There is little point in making power available if it cannot be utilised.

The fact that the value of power is far greater than its cost means that it is wise always to have a little more capacity than you need, because the cost of running short far exceeds the cost of holding a little excess capacity. But it does not follow that you must create significant excess capacity in the hopes of driving development. That has been tried on several occasions, and we know it is not a successful strategy.

Another necessary condition for growth is the means to transmit power from where it is generated to where it is needed. *Figure 4* shows the transmission grid in Southern Africa [4], with blue lines showing existing transmission and red dashed lines – the planned extensions. There are at present comparatively few cross-border links, and those that exist are generally of limited capacity. At present, Angola has essentially no grid, while Kenya, Tanzania and Malawi are independent, although links are planned. It is most desirable that cross-border links be created. European experience shows clearly how reliability of supply can improve when there is a high degree of interconnection, even though the net power transferred over a year is quite small. Indeed, it is interesting that while South Africa is a major power producer, it is effectively in balance with its neighbours, importing as much as it exports.

Even though transmission is in place, and there is effective local distribution, it must not be assumed that the arrival of power will result in an immediate surge in demand. It takes time to assimilate new sources of energy. A review of the South African experience shows [5] that it took about seven years after the first arrival of electricity for homes to be reasonably electrified. The early uses were low-power needs such as radio, television, computers and telephones; slowly small domestic appliances like irons and kettles were acquired; and only after a few more years the first major appliance, which was usually a refrigerator, was purchased. Creating local distribution is not cheap, and it takes time to start to recoup the investment in the system, which is something that must be borne in mind as there is more widespread power throughout the region.

Conclusion

The availability of sufficient electrical power is one of the key factors in facilitating economic growth. Sub-Saharan Africa is desperately short of power, and is poor as a result. Meeting its needs will demand investment of hundreds of billions of dollars, but the return on this investment should prove excellent because the value of power far exceeds its cost.

Many of the nations of the region are blessed with the natural resources necessary to produce power cheaply – Tanzania, Mozambique, Angola and others have adequate supplies of natural gas; the Democratic Republic of the Congo has huge hydropower potential; and Botswana has an enormous and largely untapped coal resource. A recent assessment of Africa's energy potential [6] notes that the present reliance on biofuel as a source of energy is creating huge environmental impacts. The impacts include loss of a carbon sink due to deforestation, aerosols from charcoal production and indoor air pollution from open fires. It is preferable to use more fossil fuel than to continue to rely on biomass energy.

Africa has the resources. It now needs the courage to develop them.

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A need for energy, both real and perceived, has been the driver of electrical innovation for well over a century. Whereas much can be done to optimise what we already have, the opportunities (especially in Africa) are driving a new wave of innovation. To appreciate this, it is important to review our past.

1

Power electrical systems – progress over time

H du Preez, Consultant

Power savings in transformers and motors is an area where there have been a number of improvements in the past few decades – with room for more. Various figures are quoted when the equipment that uses the most electricity is considered. It is said that between 60 and 70% of the total electricity generated is used by electric motors in some form or other.

As most of the power used in the country is generated in particular areas, a distribution system is required – which means transformers and transmission lines.

South Africa's power is predominantly generated by coal – causing CO_2 emissions that pollute the atmosphere. Saving electricity actually reduces pollution. Alternative environmentally-friendly generation systems such as solar, wind, wave and hydro also come with their particular problems and limitations.

At the turn of the 20th century, 1903 and onwards, electricity was in its infancy with direct current (dc) systems and research into alternating current (ac) just beginning. Dc motors and dc generators were

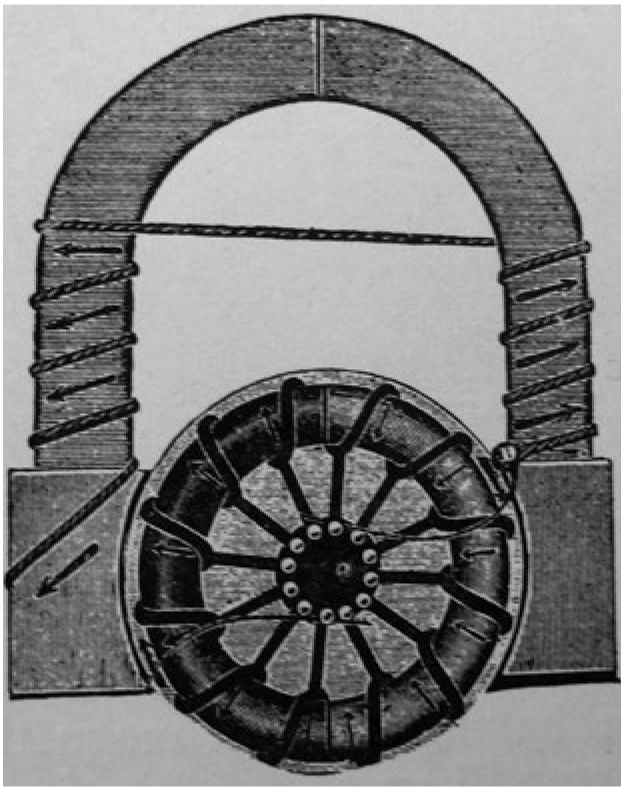

Figure 1: Ring Dynamo.

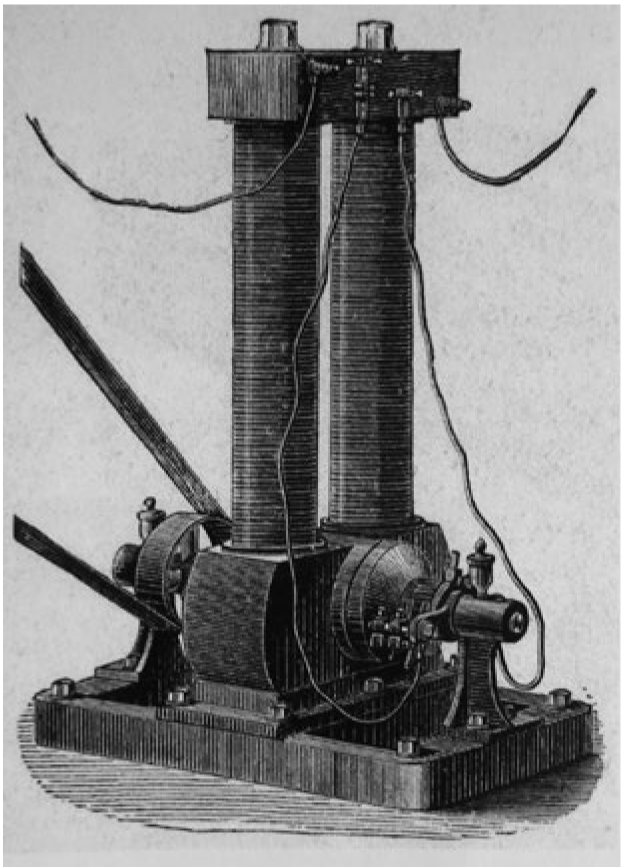

Figure 2: Early dc machine.

the norm. Convenience rather than efficiency was the consideration – light at the turning on of a switch and power away from the water wheel or steam engine. The incandescent lamp comes from this era.

When ac power started to make its mark, it was realised that power could be saved; for example, an ac arc lamp requiring 8 Amps (A), 30 Volts (V) and 240 Watts (W) but with a 110 V supply, a resistor would be connected in series; the power in the resistor would be 640 W wasted power until a choke coil was developed using a coil wound over an iron core, dropping the voltage with a much smaller power loss. This system obviously only works when an ac system is employed.

As we progressed through the 20th century, technology and materials advanced to improve efficiency and reduce wasteful systems.

Materials: Materials have been improved and with better use and design, savings are realised.

Electrical steels: The attraction of flux magnification and its dividend of force control was central to early machine design, but as the electrical industry grew, the spotlight turned to energy efficiency.

Engineers… does the 'Solar Sphere' improve collection of solar power?

In the earliest electrical machines, solid iron cores were used, cast or wrought, but the benefits of lamination in reducing eddy currents rapidly became apparent.

Higher magnetic grades of steel which improve efficiency must be included as a major factor considering the urgent need to diminish wastage of energy, conserve finite resources and reduce the release of pollutants. Improved higher grades of steel also enable machines to be reduced to more manageable sizes.

Reduced size is clearly associated with reduced energy wastage in exciting conductors. In pursuit of a greener world there is a pressure and interest in pumps, fans and other drives to use speed control which improves efficiency and reduces waste. Speed control throttling of the output, a very wasteful practice, can be avoided. The means of speed control offers fresh challenges to the motor manufacturers to accept a wide range of input frequencies without themselves creating excessive losses.

High speed motors mean smaller and lighter machines, able to deliver increased power output, lamination steel and Variable Frequency Drives (VFDs), critical to achieving these benefits.

Transformer lamination steel

In the past 70 years the development in lamination steel, as well as amorphous alloys, has reduced the losses significantly.

Transformers for power distribution experience two pressures. The first is for reduced first cost to fit in with short term budgeting; the other is to be super efficient so the life time ownership costs are minimised and green performance optimised. In the early 1940s, losses in conventional grain-oriented steel at 1,7 Tesla were around the 2 W per kilogram (0,35 mm thick laminations). Currently, domain refined laser, etc, (at 0,23 mm thick), losses are below 1 W per kilogram.

Amorphous alloy is a very thin material with losses between 0,2 and 0,3 W per kilogram at 1,5 Tesla. Amorphous metals have come into the electro technical arena, displaying their unique capabilities, but have yet to have all the possible applications and potential benefits developed.

This material is ideal for transformers where the duty cycle is low. We have an abundance of distribution and small transformers throughout South Africa and in these applications we find a low duty cycle – unlike power transformers. The iron (no-load losses) in a transformer with a duty cycle of 30% forms 80% of the total losses of a transformer.

Solid cast iron was useful for some parts of dc machines, but thinner section material was soon in demand for transformers and those parts of rotating machines that carried rapidly varying magnetisation.

The advantages of the addition of silicon not only reduced eddy currents, but the effective field permeability of the alloy was enhanced and other advantages were evident.

Electric steel came into being in response to a need for magnetic flux enhancers. Excessive power loss owing to lower magnetic grade steel meant the core steel became hot and magnetic ageing was accelerated. The cost of energy has become such that efficiency is an important factor from an economical and competitive point of view.

Electric motors

The majority of electric motors are ac motors. Since electric motors account for 60 to 70% of the electric power energy generated in industry, it makes sense to explore different methods to improve efficiency in the consumption of electricity. Improving the efficiency of the motor helps, but it is comparatively small compared to the energy wasted by running motors at low – and even on no load – for long periods.

Induction motors are fixed speed machines dependent on the frequency of supply. Until recently, speed control could only be achieved with slip-ring motors where the resistance of the rotor was changed using an external resister. This was wasteful of power. Later, power was recovered using power electronics in a feedback system where the power from the rotor of was fed back into the system.

Owing to variable duty cycles, many motors run at less than 50% of their capacity for much of their duty cycle. It is well known that induction motors are unintelligent and that in these off-load parts of the duty cycle they consume much more electricity than they actually need. There are full iron losses and a higher I^2R loss owing to the fact that the Power Factor (PF) is poor in a motor running at no-load or at light loads.

The advance in power electronic and computer technology has enabled more effective control systems where frequency and voltage feeding the motor can easily be controlled and optimised, enabling power savings.

Induction motors can be controlled so that the speed optimises the load requirements by adjusting the speed accordingly; further savings can be achieved by reducing the voltage according to the load requirements. To take into consideration the possibilities of high frequency induction motors, motor steels will become thin and pure with low alloy. Therefore the rising frequency regime can be faced without too great a sacrifice of efficiency via core loss, and too great a burden of copper loss through impaired permeability. The possibility of obtaining grain texture and orientation should not be ruled out, bringing additional benefits.

Electro technology – at well over 100 years old – is due for a radical breakthrough. The sky's no longer the limit!

This excess consumption is not only an unnecessary burden on the energy bill, but it damages the equipment and motor as the excess energy released is through the winding and core of the motor in the form of heat, vibration and noise.

Power electronics in induction electric motor efficient operation

There are VFD systems that not only vary the frequency, and therefore the speed, but have facilities to monitor the load and adjust the voltage to optimise the power usage.

VFD operation of induction motors gives a number of benefits in power saving as they are able to optimise and control the speed of the driven equipment. There are other benefits that can be obtained by controlling the input voltage to the motor because of this unique characteristic of ac induction motors.

- Reducing speed eliminates the necessity of throttling and wasting power
- Reducing voltage moves the PF curve to the left resulting in reduced current, reduced current due to the improved power factor and reduced voltage reduced I^2R losses (copper losses)
- Reducing voltage reduces flux density in the iron (laminations) reducing iron loss
- VFD systems reduce the stresses on the motor as they are effective soft start devices. The low frequency start controls the current and torque produced by the motor which results in low current and not the six to 10 times starting current found in DOL motor starting systems
- Mechanically this is beneficial as there is no shock load applied to the mechanical system such as coupling, shafts and load

Transmission lines and the distribution system

In the early days of commercial electric power, transmission of electric power at the same voltage as used by lighting and mechanical loads restricted the distance between generating plant and consumers. In 1882, generation was dc, which could not easily be increased in voltage for long-distance transmission. Different classes of load (for example, lighting, fixed motors, and traction and railway systems) required different voltages, and so used different generators and circuits.

When the ac system was introduced, transformers developed that enabled voltages to be increased and decreased as required assisting in facilitating transmission over long distances.

Losses in transmission line are related to I^2R so reducing the current reduces the losses proportionally to the square of the current whereas the power is proportional to the product of voltage and current.

With power electronics, high voltage dc systems are available which greatly decrease losses over long transmission lines. The ac generated power is increased to very high voltages, rectified and transmitted via a dc line and converted back to ac using inverters where it can be transformed to any required voltage.

With very high dc voltages corona discharge becomes a problem and the losses can offset the advantages. Steps can be taken to reduce the corona losses.

Illumination

We have progressed from sunlight and fire to candles to gas, arc, incandescent and fluorescent lamps and now to LED lighting systems. LED lighting saves power. It is expensive to install initially but costs have come down and, as time goes by, they will come down further. The life expectancy for these lamps is long and power savings large.

Conclusion

Looking to the future, generation of power is an area where the environment is negatively affected if we continue with the old coal fired boiler power stations. Yes, there is pollution control on these systems, but it does not solve the problem.

Efficiency of motors and transformers is moving forward but it cannot be looked at in isolation. The entire system must be considered. It serves no purpose to use a premium efficiency motor in an application where the motor runs on no – or very light – loads for 50 or 60% of the time; an alternate solution must be found. In distribution transformers that are loaded for short periods, iron losses become very important.

Evaluate loads using a systems approach. A piece of equipment in isolation is not effective and the application and system must be considered.

New materials are being developed but the challenge is how to best use these materials in the machines.

1

The electrical sector is a regulated and relatively conservative sector – for a good reason. The opportunities that renewable energy sources offer in the sub-Saharan Africa arena have encouraged regulation to reflect on how to incorporate these technologies, and Independent Power Producers in general, into the existing grids.

Large-scale Renewable Energy power opportunities: Africa

C Paton, Frost & Sullivan Africa

Following a global trend, governments in most sub-Saharan African countries have set up Renewable Energy (RE) targets for their power sector that are becoming increasingly ambitious. According to the REN21 Renewables 2015 Global Status Report [1], as of early 2015 most of the countries in sub-Saharan Africa have already set up official RE targets with the exception of Angola, Burkina Faso, Cameroon and Zambia. The latter is rather unexpected and most likely explained by the fact that 99% of its power installed capacity already comes from renewable sources (i.e. hydropower).

Even when including the national electrification rates of South Africa (85%) and Ghana (72%), which are currently the highest in sub-Saharan Africa, the average electrification rate at national level remains as low as 30%. This is despite an annual average GDP growth context of about 4-5% as shown by the latest forecasts from the International Monetary Fund (IMF). One cannot hide the fact that power deficits are, and will remain, a core obstacle for socio-economic development in sub-Saharan Africa within the next decade.

Wind, solar, geothermal

Thanks to their cheap and environmentally-friendly operating costs (no fuel costs), falling technology and capital costs, as well as short construction lead times compared to traditional fossil fuel power plants, wind, solar and geothermal technologies are gaining momentum in Africa.

Thereby, massive investments in solar and wind power have been taking place in the past three years in South Africa with the successful implementation of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). These technologies have also been gaining strong ground in North Africa, with Morocco and Egypt taking the lead by implementing large grid-connected solar and wind power projects.

What can we expect from the rest of Africa?

Next to this, the logical question that one could raise is: What can we expect from the rest of Africa? This has been the purpose of the analysis report, titled 'Large-scale RE power development opportunities in sub-Saharan Africa – A story about bankability, affordability, and grid capacity (2015)' [2]. The study [2] identifies countries with the highest opportunities in terms of grid-connected RE resources, combined with a series of other factors such as the countries' regulatory, political, and economic landscape. The research focused on four different RE technologies: Solar photovoltaic (PV), Concentrated Solar Power (CSP), wind, and geothermal. Hydropower was excluded as many countries, especially those suffering from severe drought in Eastern and Southern Africa, are trying to diversify their electricity generation mix to include more non-hydro renewable energy sources, which are less prone to climatic changes. As stated previously, most countries in sub-Saharan Africa are facing a power deficit or need to build additional power generation capacity in order to address a strong economic growth or to replace ageing power plants. The gap between power supply and power demand is less important in certain countries compared to the others (especially countries with lower population density such as Botswana and Namibia).

Nevertheless, ideal geographic locations combined with strong natural resources can offer an opportunity to export their power surplus to neighbouring countries or to regional power pools where the deficit is larger. So far, regional power trades have remained limited, with the Southern African Power Pool (SAPP) being the most active as of today.

Emphasis is currently placed on reinforcing intra-regional power transmission networks, especially in Eastern Africa where one of the main active projects includes the Ethio-Kenyan transmission line project which aims to build a 433 km transmission line between Ethiopia and Kenya, with the intention to export Ethiopian power further into the Eastern African region. This will constitute an important prerequisite to implement successful, sustainable, and diversified large-scale RE power sources.

New opportunities

Following the recent success of the South African REIPPPP, the strong global fall of RE technology costs, and the available RE stock/services surplus from a financially constrained European power market, many international (RE) power developers decided to look for new opportunities elsewhere, including in Africa. Large economies of scale (with the auctioning of solar and wind power projects of several hundreds or even thousands of megawatts) combined with a clear regulatory and institutional framework, as well as a strong will (i.e. which concretises into action) from governments to implement large amounts of RE power technologies in a relatively short timeframe, have favoured North and South Africa. Now, many developers are showing a growing interest to develop their activities in the rest of sub-Saharan Africa. Many private equity funds have been set up with the intention to invest large amounts of money into clean energy infrastructure projects across sub-Saharan Africa. Power demand remains; however limited in most countries and, therefore, does not allow the economies of scale benefitting RE developers in North and South Africa. Nevertheless, there is a plenitude of 'smaller' opportunities across the region. It will be more a matter of finding an efficient way to finance them or to 'scale them up' in order to improve the bankability of such projects.

Challenges

Sub-Saharan Africa is endowed with large, untapped RE resources including, but not restricted to solar, wind and geothermal power sources. An increasing number of solar and wind RE power projects are currently being developed in the region. However, among the utility-scale ones, very few have reached financial close. The main challenges to building large-scale grid-connected RE power projects in sub-Saharan Africa (excluding South Africa) are as follows:

- Projects' bankability
- Limited grid capacity
- Electricity affordability

The process to negotiate a Power Purchase Agreement (PPA) with the power utility and to achieve the required land permits often takes many years. Opposition from local communities living in the vicinity of such projects is not to be underestimated. Indeed, access to land has been an issue lately for large RE power projects, especially in Kenya and Ethiopia, but also in South Africa. Commercial financial investors will often require sovereign guarantees owing to the low credit-worthiness of power utilities.

Certain governments are not capable of providing such guarantees as they can only commit to weak letters of support. This is where the intervention of political and commercial risk guarantees comes into play – at additional costs, with the intervention of development finance institutions and export credit agencies such as the World Bank (i.e. MIGA, IDA, IBRD, IFC), the African Development Bank, as well as the African Trade Insurance Agency.

Grid connectivity and an insufficient capacity to integrate variable power, or a lack of understanding of the impact it could create on the grid, are other key restraints that many sub-Saharan African countries are facing (e.g. Ghana which is currently imposing a temporary cap of 150 MW for its large-scale grid-connected solar PV projects).

Finally, non-cost-reflective electricity tariffs are often unattractive to private power generator investors. In addition, these tariffs do not provide enough resources to power utilities to make the necessary changes (rehabilitation and expansion) to the grid, often required to accommodate RE power projects.

Electricity tariff subsidies prove to be ineffective as most power utilities do not have the adequate means to secure a stable power supply to their consumers. New business models need to be put into place to ensure:

- Higher access to electricity
- Cost-reflectiveness
- Affordability and competitiveness of electricity tariffs across the continent

Moreover, the tradition of having fossil fuel subsidies in place in certain countries, such as Nigeria, distorts the competitiveness of RE power projects, not reflecting the real levelised cost of electricity of thermal power plants.

Operating IPPs

Having suitable RE resources is therefore not sufficient. In addition to the elements cited, investors and developers must also be wary of the country's Independent Power Producers' (IPPs) track record. *Table 1* summarises which countries in sub-Saharan Africa have operating IPPs. The next step is to evaluate if the IPP experience has been fruitful or not.

In terms of procurement and contracting mechanisms, the global market trend is currently favouring a competitive bidding process – such as what has been implemented in the South African REIPPPP – even though Renewable Energy Feed-in Tariff (REFiT) continues being adopted mainly in emerging markets. This is the case of Kenya, Uganda, Tanzania, Rwanda, Nigeria, and Ghana, which have all implemented REFiTs.

Some countries are also adopting a mix of REFiT and competitive bidding such as in Kenya, Uganda, and Tanzania. REFiTs are sometimes limited to certain types of technologies such as small hydro and biomass like in Tanzania and Rwanda. The report [1] has combined eight different quantitative factors including the legal and political framework, the economic and infrastructure development, as well as a natural resource assessment [3] performed by the International Renewable Energy Agency (IRENA) to identify countries with the best opportunities in terms of large-scale grid-connected RE power technologies. Small-scale (defined as smaller than 5 MW), off-grid, and embedded RE generation projects have not been accounted for and their potential should be considered in addition to the findings from this report.

Results of the research indicate that best opportunities lie in South Africa, but also in Tanzania, Namibia, Kenya, Zambia, Nigeria, and Ethiopia, depending on the RE technology (limited to CSP, solar PV, wind, or geothermal). Despite not being in the top five ranking, Ivory Coast and Ghana have also been identified as countries which deserve particular attention for their large-scale solar PV potential.

In 2014, total RE power installed capacity (including hydro and biomass) amounted to 27,6 GW in sub-Saharan Africa. Hydropower represents 85,8% of this amount. Nevertheless, geothermal, solar PV, and wind power witnessed the highest growth compared to the previous year, progressively eroding hydropower market share.

As of June 2015, the pipeline of large-scale RE (solar PV, CSP, wind, and geothermal only) power projects (larger than 5 MW and excluding North Africa, South Africa, and the African islands) amounted to approximately 14,7 GW. Only 647 MW started the construction phase, the rest being in earlier stages of development.

Table 1: Countries with IPP presence.

Renewable Energy Support Policies

Historical IPP Presence

Countries with IPP Presence, Sub-Saharan Africa, 2015

	IPP Presence
Angola	IPP Present
Benin	IPP Not Present
Botswana	IPP Presence Soon
Burkina Faso	IPP Presence Soon
Burundi	IPP Present
Cameroon	IPP Present
Central African Republic	IPP Not Present
Chad	IPP Presence Soon
Congo-Brazzaville	IPP Not Present
Cote d'Ivoire	IPP Present
Dem. Republic of Congo	IPP Present
Djibouti	IPP Not Present
Equatorial Guinea	IPP Not Present
Eritrea	IPP Not Present
Ethiopia	IPP Presence Soon
Gabon	IPP Present
Gambia, The	IPP Present
Ghana	IPP Present
Guinea	IPP Not Present
Guinea-Bissau	IPP Not Present
Kenya	IPP Present
Lesotho	IPP Not Present

	IPP Presence
Liberia	IPP Not Present
Madagascar	IPP Present
Malawi	IPP Not Present
Mali	IPP Not Present
Mauritania	IPP Not Present
Mozambique	IPP Presence Soon
Namibia	IPP Presence Soon
Niger	IPP Not Present
Nigeria	IPP Present
Rwanda	IPP Present
Senegal	IPP Present
Sierra Leone	IPP Present
Somalia	IPP Not Present
South Africa	IPP Present
Sudan	IPP Not Present
Swaziland	IPP Not Present
Tanzania	IPP Present
Togo	IPP Present
Uganda	IPP Present
Zambia	IPP Present
Zimbabwe	IPP Present

IPP Present
IPP Presence Soon
IPP Not Present

A good track record of IPPs, either for renewable or non-renewable technologies, is an important supporting factor to consider as it will help accelerate the involvement of future IPPs aimed to develop large-scale RE power projects. A lot of countries have put into place reforms to liberalise their electricity sector and open power generation to IPPs.

Source: Frost & Sullivan

Solar PV is by far the most popular technology in development to date, followed by wind, geothermal and CSP. Despite the small amount of MW under construction, significant progress occurred since the beginning of 2014 with some flagship projects being commissioned such as the Olkaria I-III-IV geothermal projects in Kenya (306 MW), the first grid-connected solar PV plant in Rwanda (8,5 MW), the Adama II wind project in Ethiopia (153 MW) or large projects having reached financial close such as the Lake Turkana wind project in Kenya (310 MW). This is in addition to the 1 800 MW of grid-connected solar and wind power projects having been commissioned in South Africa under the REIPPPP.

There is still a shortage of expertise among government decision-makers and the relevant public institutions in sub-Saharan Africa. Corruption is still present in a lot of countries. Poor long-term planning often obliges governments to implement expensive short-term solutions. The lack of a clear and stable regulatory framework promoting private investment is jeopardising the bankability of these projects.

What the market needs is to find new creative funding schemes which will improve the bankability of RE power projects. Examples such as the IFC's recent 'Scaling Solar Programme' and the 'Scaling Up RE in Low Income Countries Programme' are going in this direction.

It is important that the power technology that will be adopted makes economic sense for the country and helps it reach a sustainable, diversified and affordable electricity generation mix. Factors such as dispatchability, construction lead times, environmental impact and benefits to local communities must be considered and compared with alternative technologies.

Furthermore, it is essential that governments strike a balance between grid-connected and off-grid power solutions, or centralised and decentralised power systems. Each country must look at its indigenous resources and what makes more sense economically, taking into consideration externalities such as fossil fuel subsidies, environmental impact, dependence on finite fossil resources, but also electricity affordability, especially for disseminated rural populations.

Conclusion

There is much optimism in the market for the development of RE power projects in sub-Saharan Africa. Countries are in various stages of liberalisation of their electricity sector. Many governments are trying to establish new regulatory frameworks and contractual structures to allow IPPs in the power generation sector, which will greatly facilitate the adoption of RE power projects. However, some issues continue to restrain the development of these projects. Strong government support, including a long-term vision, good energy planning, and a real desire to involve the private sector is essential for the successful implementation of RE power projects in sub-Saharan Africa. If one can combine these with innovative financing structures, which allow circumventing the bankability and scaling issues, then one can expect to be proud of what this will bring for our future generations

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No conversation about electrical energy could be complete without including transportation. Electric vehicles have been around since the development of storage devices, but only recently have they been seriously considered.

1

Electric mobility solutions – enormous operational energy cost savings

A English, Freedom Won

The energy efficiency of Electric Vehicles (EVs) described in this article has resulted in an operational energy cost saving of up to 90%. This is substantiated by case study data from a game lodge in Botswana, which is operating Freedom Won Electric 4x4 game drive vehicles and electric river boats.

An advanced EV drivetrain design by the company the author represents, in collaboration with the Zest WEG Group, is using highly efficient Permanent Magnet (PM) motors and a direct current (dc) input version of the WEG CFW 11 three phase inverter. This system has been installed in various conventional vehicles by removing the original engines and fitting in their place a combination of electric motor, motor controller (inverter) and lithium batteries.

Figure 1: A 2010 Fiat500 which has been converted to pure electric drive.

The substantial reduction in operational costs results not only from the fact that the energy input cost is as little as 10% of a conventional vehicle, but because there is no drivetrain maintenance on these EVs.

Chobe Game Lodge in Botswana is operating two Electric Land Rovers and an electric boat. These vehicles are used for game viewing excursions around the Chobe National Park and on the Chobe River. The lodge records the monthly energy consumption on its electric fleet and is able to compare this to the consumption figures achieved by the same vehicles before they were converted. This data has been used as real world unequivocal evidence of the excellent possibilities for reduction in energy consumption and carbon generation by using EVs.

As a result of the extremely positive data obtained as well as the obvious benefit of a silent electric game drive vehicle, the management of Chobe Game Lodge has started the process of converting its entire 4x4 and boat fleet to electric power.

Talking efficiency

The energy efficiency of EVs is about 83% comparing the energy used to charge the vehicles to the energy ultimately transferred onto the vehicle drivetrain. This compares to 25% for petrol engines and 40% for diesel engines in terms of the efficiency for converting fossil fuel energy placed in the tank to useful mechanical energy. These efficiencies are based on a steadily running engine under a constant load. A petrol or diesel internal combustion engine will exhibit far lower overall efficiencies in the real world, where stopping, starting and idling occurs frequently. The efficiency drop under these conditions with an electric vehicle is by contrast very small.

The more efficient transfer of energy to the vehicle drive system means lower cost of operation. The use of solar energy to charge EVs eliminates direct costs and operational CO_2 gas generation altogether and relies purely on an upfront investment in a photovoltaic array and a stationary battery for night time charging.

The 83% efficiency is very much the leading edge in EV design and is made possible by the WEG 'Wmagnet' PM motor with an efficiency of 95,3% [1] the WEG CFW11 Inverter of 97% [2], the charger of 93% [3] and the 'round trip' (charge – discharge) efficiency of the Lithium Iron Phosphate cells of 97% [4]. The formula therefore is:

Overall Efficiency = 0,95 x 0,93 x 0,97 x 0,97 = 0,83, or 83%.

Figure 2: PM motor attached to the Land Rover Defender Transfer Case with a special adaptor housing ready to be installed into an EV Conversion.

Slow driving through the game park in sandy conditions accentuates the efficiency comparison because the WEG PM motor maintains its efficiency of 95% through most load and speed scenarios, whereas a diesel or petrol motor becomes significantly less efficient in such an erratic and high-load drive profile.

Figure 3: The WMagnet motor range by WEG, as used in Freedom Won's electric conversions, is driven by the CFW11 range of inverter. (Image courtesy WEG).

Case study data

Table 1 summarises the data received from Chobe Game Lodge (CGL). Freedom 3 is its first electric Land Rover, which has been operating since August 2014. Freedom 4 is its first electric boat, and Freedom 5 is its second electric Land Rover. The Land Rovers are Defender 130s with game viewing configuration for 11 seats. The boat is a 9 m long twin hull flat deck boat with capacity for 18 passengers.

Table 1: Chobe Game Lodge Energy Consumption and Carbon Generation Case Study Data updated July 2015.

Parameter	Electric Land Rovers		Electric Boat
	Freedom 3	Freedom 5	Freedom 4
In operation since	September 2014	April 2015	November 2014
Distance travelled / hours operated on electric power	10 541 km	4 634 km	535 hrs
Total electrical energy consumed	3 773 kWh	1 666 kWh	1 684 kWh
Energy consumed per km or hour	0,36 kWh per km	0,36 kWh per km	3,14 kWh per hr
Cost per kWh for Victoria Falls Hydro Power at CGL	ZAR 0,55		
Cost per km or hr	ZAR 0,20/km	ZAR 0,20/km	ZAR 1,74/hr
Fuel consumption prior to electric conversion	18l/100 km	18l/100 km	2,15 l/hr
Cost per km or hr prior to conversion	ZAR 1,81/km	ZAR 1,81/km	ZAR 21,6/hr
Total CO_2 emissions avoided	4 951 kg	2 176 kg	2 672 kg

Data in *Table 1* shows that the electric Land Rovers are so efficient that the cost of purchasing their energy is a little over 10% of what it costs to purchase fuel for a diesel powered equivalent. The hydroelectricity is less costly in the Chobe region (Pula 0,45) but in South Africa the effect of our more expensive electricity is mostly counteracted by our more expensive diesel – and the result is very similar.

Figure 4: 88A CFW 11 mounted into the Chobe Game Lodge electric boat (Freedom 4) console along with the battery management system, chargers, 12 V battery and other electrical equipment.

Figure 5: 30 kW WEG PM motor fitted to an outboard stem on the Chobe Game Lodge electric boat. (Cover has been removed for photo).

The objective for EV operators should be to install a photovoltaic array that can charge the EVs at a fixed cost of about ZAR 0,80 per kWh on a life cycle amortised basis. This feature also allows the operator to shift to a zero operational CO_2 emissions scenario.

The featured 4x4 electric vehicles will be averaging nearly 2 000 km per month each over the coming years and they will be joined by a further 10 electric Land Cruisers and another five electric boats. The entire lodge will operate on electric mobility with a total of about 20 000 kms covered by the 4x4 vehicles and 600 hours of boat operation per month. This will equate to about 9 400 kg of CO_2 emission savings for the 4x4s and 3 000 kg for the boats per month.

Return on Investment

In the case of Chobe Game Lodge, the cost savings of converting its whole fleet to electric drives are only a bonus, the real interest is in pioneering eco-tourism and offering guests a unique silent and pollution free game viewing experience.

1

Table 2: Analysis of EV savings and NPV over a 10 year period.

Year from Start	1	2	3	4	5	6	7	8	9	10
Actual Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Electrical Energy Cost per km	R 0,20	R 0,23	R 0,27	R 0,31	R 0,36	R 0,42	R 0,49	R 0,57	R 0,66	R 0,76
Diesel Energy Cost per km	R 1,81	R 2,10	R 2,44	R 2,83	R 3,28	R 3,80	R 4,41	R 5,12	R 5,93	R 6,88
Energy Savings per km	R 1,61	R 1,87	R 2,17	R 2,51	R 2,92	R 3,38	R 3,92	R 4,55	R 5,28	R 6,12
Maintenance Cost per km	R 1,00	R 1,10	R 1,21	R 1,33	R 1,46	R 1,61	R 1,77	R 1,95	R 2,14	R 2,36
Total Savings per km	R 2,61	R 2,05	R 2,62	R 3,34	R 4,27	R 5,45	R 6,95	R 8,87	R 11,31	R14,44
Annual Savings per km	R 62 640	R 49 305	R 62 913	R 80 277	R 102 433	R 130 704	R 166 779	R 212 810	R 271 545	R 346 492
Cumulative Savings	R 62 640	R 111 945	R 174 857	R 255 134	R 357 567	R 488 271	R 655 050	R 867 860	R 1 139 406	R 1 485 898
NPV of Savings per year	R 62 640	R 96 504	R 129 948	R 163 454	R 197 481	R 232 472	R 268 860	R 307 075	R 347 548	R 390 721

Table 3: NPV of Electric Land Rover conversion.

NPV of Savings Total over 10 years	R 668 787
Less Initial Conversion Cost	R 360 000
NPV of Conversion to Electric Drive of One Land Rover Defender	R 308 787

Doing good for our environment by reducing our energy consumption and CO_2 emissions should already be a substantial motivation for any business to implement EV programmes; however it almost always needs to display good economics to be widely attractive.

In the case study scenario, the initial investment for the electric conversion is recouped within a five year period. Taking one of the electric Land Rovers for instance, the initial investment to convert one of the existing vehicles to electric is ZAR360 000.

The saving in energy amounts to ZAR1,61/km. The saving in maintenance is conservatively estimated at ZAR1,00/km. This is ZAR62 640 saving per annum for a typical 24 000 km annual usage. Given that diesel costs will continue to rise annually the cost to operate a comparison diesel vehicle will increase by substantially more than an EV in absolute terms even if the percentage annual increase of electricity and fuel costs are similar. In *Tables 2* and *3* the investment payback is demonstrated including the Net Present Value (NPV) of the future savings over a 10 year period. By the end of year five the cumulative saving is ZAR357 567, essentially as much as the initial investment. The NPV of the conversion is provided in *Table 3* as ZAR308 787, which provides a compelling investment proposition.

The discount rate used is 15%, while it is assumed that the cost of both electricity and diesel will increase by 16% pa. It is assumed that the cost of maintenance will increase by 10% pa.

Conclusion

The EV conversion concept described presents fleet operators with a solid business case for converting their fleets (or part thereof) to electric drives. The tremendous improvement in energy consumption efficiency partly brought about by advanced technology developed, ensures robust operational savings while contributing in no small measure to the reduction of CO_2 emissions and burning of fossil fuels. The natural route for EV operators is to charge their vehicles from their own photovoltaic power generation plants, which would satisfy much or all of their other energy needs.

The economic benefits underpin other key benefits to the operator, such as a silent game drive experience offering to guests, that enhances a lodge operator's value offering – just to mention one example.

Note: All images – supplied by Freedom Won, unless otherwise stated.

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Photovoltaic solar panels are wonderful devices that provide an energy source that should be a vital part of any exposed roof. They are most efficient at a perpendicular angle for the sun's rays. It is perfectly viable to track the diurnal movement of the sun, optimise the solar energy captured – and convert it to electric energy.

1

Experimental efficiency comparison between fixed and tracked photovoltaic solar panels

G Craig, Techlyn

As a company with vast experience in measurement work as well as mechatronics, this project presented an opportunity to use both competencies on an energy related project. The experiment was carried out specifically as a report for 'Energy Efficiency Made Simple, Vol IV'.

Two small photovoltaic (PV) panels measuring 100 X 90 mm were to hand. The Techlyn office is located at approximately 26 degrees South and 28 degrees East. We decided to mount one panel on a fixed bracket so that it would be normal (90 degrees) to the sun's rays at 12:08.

The other would be mounted on an equatorial mount (parallel to the earth's axis) and coupled to a one revolution per day (siderial) drive. This method would enable the PV panel to track the diurnal movement of the sun.

A data logger would record the two panels' outputs for a full day. The total energy absorbed would be graphed and compared.

The mechanism

The principle of a diurnal equatorial mount is shown in *Figure 1*. The panel is spun on a shaft that is parallel to the earth's axis. The panel is mounted at an adjustable angle such that it is normal to the sun's rays. The (siderial) drive motor (one revolution per day) keeps the panel facing the sun's rays. This method is used for astronomical telescopes.

An alternative method would be to use sensors to track the sun's position and steer the PV panel with a servomotor. The problem is that cloud cover diffuses the sun's rays, rendering this method useless under cloud cover. One could defeat this condition and keep the panel stationary until the clouds passed. This seemed unnecessarily complicated, as well violating the (K)eep (I)t (S)imple (S)tupid (KISS) principle.

The sun's elevation at midday does not remain constant, but varies (in Johannesburg) from 88 degrees above the horizon on 21 December (Summer Solstice) to 40 degrees on 21 June (Winter Solstice).

If the pane elevation were set to 64 degrees which corresponds to the equinoxes (21 September and 21 March), the maximum error

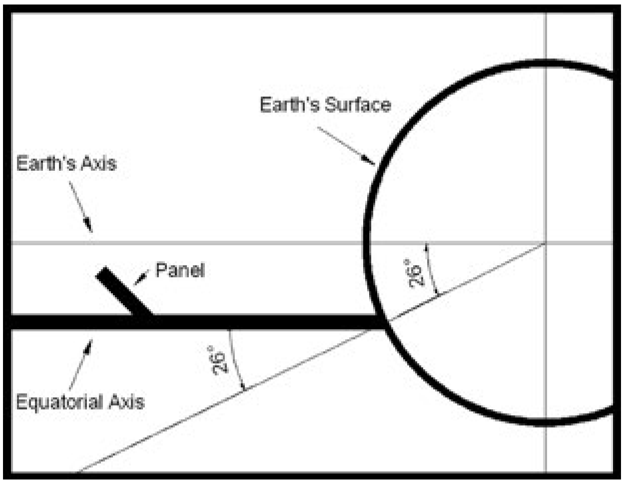

Figure 1: Principle of a diurnal equatorial mount.

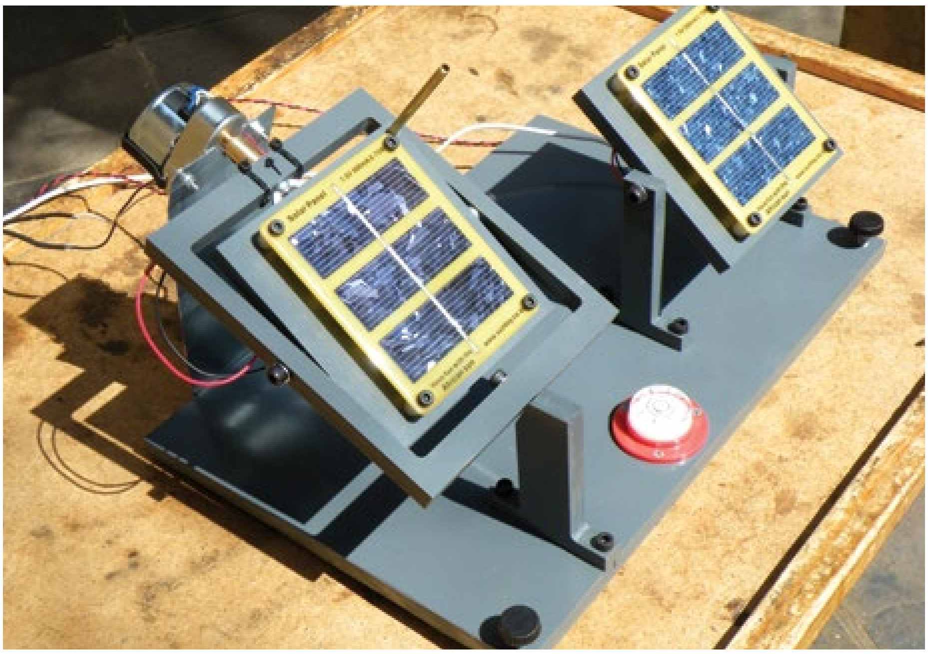

Figure 2: Test unit.

would be 88 – 64 = 24 degrees. The loss due to misalignment is proportional to the cosine of the deviation from normal. Cos24 = 0,9135 which represents a loss of 8,6455%.

A simple way around this would be to make a manual adjustment of the panel's elevation occasionally.

The system could be synchronised daily by returning the array to the vertical position (corresponding to 6:00) after sundown, ready for the next day). Rotation would commence at 6:00 facing East.

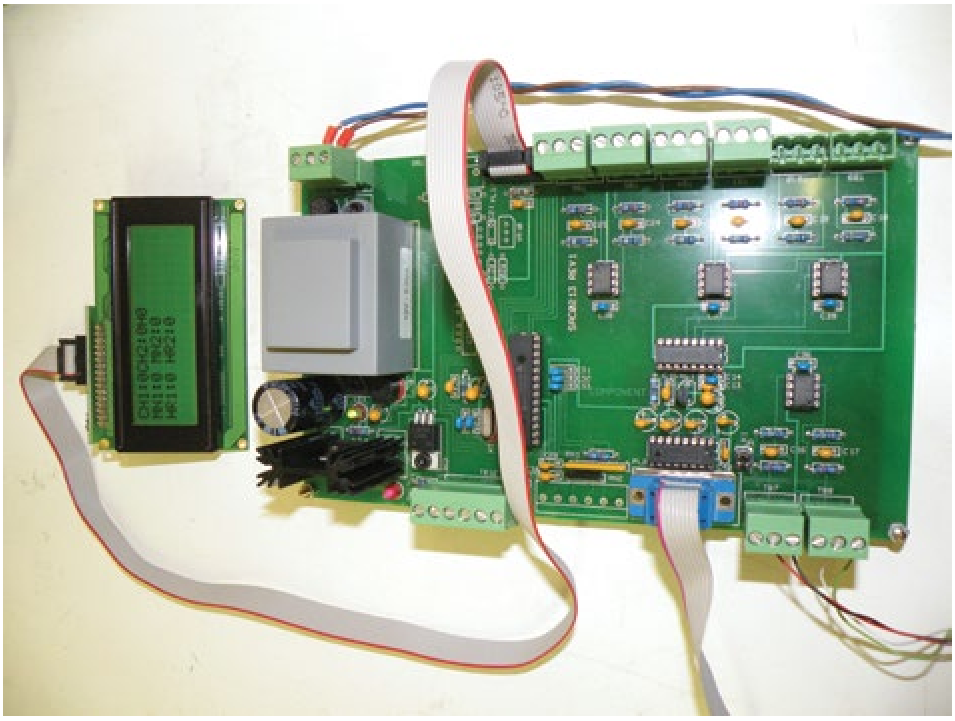

Figure 3: Connections to a datalogger board.

Test rig construction

Figure 2 is a photograph of the test unit. On the right hand is the fixed panel and the rotating panel is on the left. Note the black levelling screws and the red bull's eye spirit level used to level the rig. All parts were machined on the company's computer controlled router.

The outer frame of the steering mechanism is at a 26 degree angle to the (level) base and is rotated by a synchronous one revolution per day motor.

The inner frame has provision for adjustment to compensate for the seasonal variations in the sun's path. The brass pipes provide a means to align the panels at right angles to the sun at 12:08, corresponding to our position of 28 degrees East, and pointing due North. In both cases the shadow of the pipe was the size of the pipe base. At this point the motor was started.

The motor had been purchased as providing clockwise (CW) rotation and we had naively assumed that this referred to the rotation direction looking at the output shaft side. With the publication deadline looming, we discovered that the rotation was counterclockwise (CCW). 'Houston, we have an anomaly!'

We replaced the motor and fortunately all was well.

The panels were rated at 1,5 V 500 mA, so they were terminated with 2,2 Ohm resistors, giving about one Volt at midday. Both panels provided outputs within 2% of each other.

Figure 3 shows the connections to a Techlyn datalogger board. The board provides:

- Eight 12 bit analogue inputs (0 - 5 V)
- Two 12 bit analogue outputs (0 - 10 V out)
- RS232 communications port
- 4 line character Liquid Crystal Display (LCD) port
- Embedded microchip 18F252 processor

System operation

The analogue signals were read at one second intervals for one minute, then averaged. The same arithmetic was performed for an hour. Finally, the hour totals were added to give a day total. Logging started at 07:00 and continued until sundown.

Graphing was performed by the economically priced and easy to use MakerPlot program. All the system power was derived from a battery backed sinewave inverter.

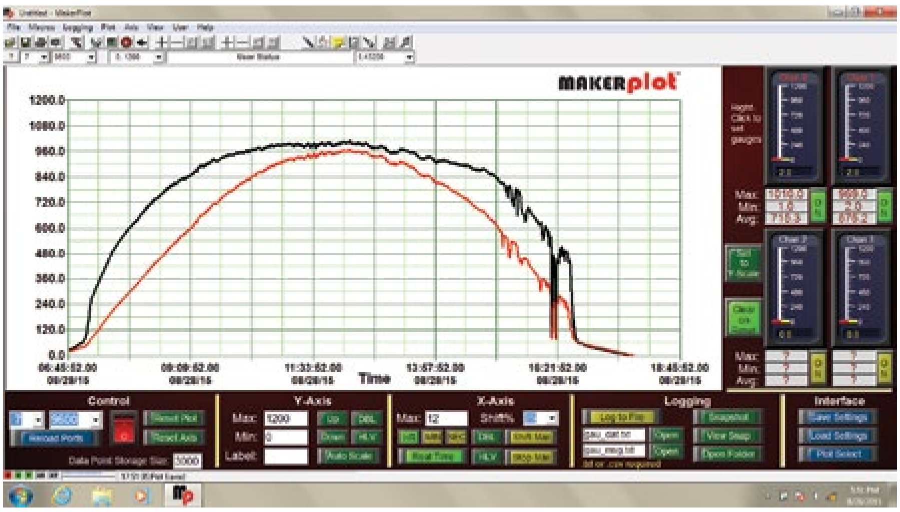

Figure 4: Plot screen. Note the built in averaging function below the meters.

The two meters at the top right show the instantaneous values. The left meter shows the steered panel output (black on the graph), while the right meter shows the fixed panel output (red on the graph).

This was the best of the logging sessions with a virtually cloudless day, with the exception of a disturbance at around 16:21. The reduced final readings were due to trees obscuring the western horizon.

For this day we can calculate the percentage gain:

Gain = (715,3 – 575,2) X 100/575,2

= 24,36%

Earlier sessions produced gains in the region of 20%. The averaging algorithm on the datalogger gave the same result.

The values represent the raw result of the datalogger's 12 bit (0 – 5 V) analog to digital converter. As we were only interested in comparative results, we made no attempt to process the readings. They are, however, proportional to milliamp hours (mAH).

Conclusion

- Different times of the year will almost certainly give different results. I intend to repeat the experiment around 21 December (summer solstice) for comparison. These data were obtained in late August
- Morning fog and pollution, as well as the oblique angle with respect to the earth's atmosphere, cause the slow start. In the morning. This could vary by season and location
- We are satisfied with our attempt to put some numbers to this concept
- Estimated costs for a full size mechanism has not been attempted, as reliability could easily be degraded by conditions such as strong gusts of wind; only a test installation would give answers

Acknowledgement

I would like to thank my colleagues Andrew Craig and Joseph Jansen for constructing the mechanism.

Dedication

This article is dedicated to the memory of the late Professor Alan Nurick, a gifted solar experimenter and a good friend.

A variety of new technologies will become key ingredients of the future energy mix – including fuel cell technology. Pilot sites are being established and we need to watch these developments as they unfold. In this way we will appreciate the value and opportunity that this technology offers. What better site than a school?

'Fuelling the future' – Developing the hydrogen fuel cell market in South Africa

P Venn, Air Products South Africa

Hydrogen fuel cell technology is 'green', emission-free, non-intrusive and virtually maintenance-free. Using the most abundant element in the universe, this technology is proving to be an effective source of back-up power in certain industries, and in remote areas. Two pilot projects are being run by the company the author represents, to ascertain just how this technology can indeed help to 'fuel the future'.

While fuel cell technology is not new, it is being increasingly recognised in the global alternative energy industry for its many, compelling advantages. Significant strides have been made in the past decade to develop the technology into a usable, viable source of clean-burning energy generation, but there is still much work to be done.

Hydrogen fuel cell technology is in its early stages and economies of scale have not yet been fully developed. There are also certain related challenges to be overcome. Commercialising the technology is in a pilot phase and the question is exactly how to upscale the pilot projects in order to create a fully viable solution.

First project: Innovation in rural schools

One of the projects involves the use of hydrogen fuel cells at three rural schools in the Cofimvaba region of the Eastern Cape. This forms part of the TECH4RED (Technology for Rural Education and Development) project, which was initiated by the Department of Science and Technology (DST) in 2012. The Cofimvaba fuel cell project, launched in July 2015, has been the result of a powerful Private-Public Partnership (PPP), which aims to enhance the quality of learning and teaching in remote, rural schools through science, technology and innovation.

In advancing the cause for hydrogen fuel cell technology through the Cofimvaba project, Air Products South Africa partnered with Anglo American Platinum, which sponsored three platinum-based fuel cell systems, and Clean Energy Investments, a South African company co-owned by the DST and Anglo American Platinum, which commissioned the fuel cells. The fuel cells are now successfully providing back-up power to the schools, specifically for the recharging of tablets that have been supplied to learners and teachers in the region.

This project will go a long way towards our understanding of how hydrogen fuel cell technology can work in a practical way, within the South African context. At this stage, it is only viable as an alternative source of back-up power, supplementing existing infrastructure, but it will enable the learners to have access to the internet 24/7, which is critical in the current power crisis.

Fuel cells were first used commercially by NASA (the National Aeronautics and Space Administration) in the early 1960s to generate power for probes, satellites and space capsules, and are now mainly used for back-up power in certain industries, such as telecommunications, and for powering fuel cell vehicles.

Ease and simplicity for the end-user

Fuel cells are devices that convert hydrogen and oxygen into electricity, providing an emission-free alternative to conventional electricity. Offering ease and simplicity for the end-user, fuel cells are extremely effective and low-maintenance: while batteries have a limited lifespan, fuel cells produce electricity on an ongoing basis, without having to be recharged. As long as there is a continual supply of hydrogen, the electrochemical conversion takes place simply and effortlessly, with only heat and water as by-products.

Fuel cells are 'green' technology, which makes them relevant in a rural school environment as well as in a wider industrial context, which is increasingly focused on reducing carbon emissions.

A hydrogen fuel cell comprises Membrane Electrode Assemblies (MEAs), placed between two flow field plates, and produces an electric circuit with an efficiency of between 40 and 60%. The MEA has an anode and a cathode, coated on one side with a catalyst layer (platinum) and separated by a Proton Exchange Membrane (PEM). Hydrogen gas and ambient air are injected into channels in the flow field plates, which then direct the hydrogen to pass over the anode, and oxygen (from the ambient air) to pass over the cathode. When the hydrogen reacts with the catalyst layer, it separates into protons (H2 ions) and electrons. The H2 protons which migrate through the PEM combine with the oxygen, forming pure water and heat. The free electrons produce a useable electric current at the anode,

These fuel cells generate 0,7 volts, and 50 cells are configured in a combination of series and parallel connections, to provide the specified regulated voltage/amperage output required. For the Cofimvaba project, the fuel cell engine output is 5 kW. The system components are managed and controlled by a Programmable Logic Controller (PLC). The PLC also monitors the power demand and can initiate anywhere between a partial to full output of energy from the fuel cell engine almost instantaneously, to meet the required set points. Each hydrogen cylinder, provided for the project, contains enough hydrogen gas to provide 10 kW of power for the fuel cell engine.

'Green' technology

Hydrogen fuel cells provide a stable power environment that is not at risk of theft, unlike batteries and generators. They are also much quieter than generators, making them non-disruptive and conducive to a learning environment.

Above all, fuel cells are 'green' technology which adds to their relevance not only in the rural school environment, but in the wider industrial context, which is increasingly focused on reducing or eliminating carbon emissions.

Fuel cell technology is undoubtedly at the forefront of energy-related technology currently available; however, its implementation involves several aspects for consideration, and the input of various stakeholders.

There is still much work to be done, for example, in terms of legislation in this country. The use of fuel cells is gaining increasing relevance globally and pilot projects, such as Cofimvaba, are vital for our understanding of the practical applicability of the technology.

Challenges facing the development of hydrogen fuel cell technology include changing legislation and changing corporate and industrial standards (both locally and internationally) relating to risk control mechanisms.

There are risks involved when it comes to commercialising the technology, such as ensuring that the entire installation is correctly earthed, and ensuring a safe connection between the gas supply and the fuel cell. Although hydrogen itself is not a high-risk gas, the installation at Cofimvaba necessitated certain risk mitigation factors – such as limited quantities of hydrogen on site, cordoning off of the installation to prevent tampering and theft (of small parts), and the use of a flexible hose between the manifold and cylinder which would rupture and vent in the unlikely case of fire.

Hydrogen, known as the lightest and most abundant element in the universe, has a wide flammable range (of between 4% and 75%). In the normal operation of a fuel cell installation, due to design and safety considerations, there is no risk of explosion. As it is extremely light in molecular weight, in the case of a leak, hydrogen dissipates into the surrounding atmosphere.

Uninterrupted power where it is needed most

Hydrogen technology has particular application for stand-by power in the telecommunications industry, as well as mission-critical sectors such as hospitals and clinics.

Hydrogen fuel cells have been used successfully in the US telecommunications industry as a form of back-up power supply for cell phone towers. We see great scope for this technology in the local telecoms industry. In summary, we see it in any context which requires an uninterrupted power supply - particularly in remote, rural areas.

Second project: Storing medication

A fuel cell project at a healthcare facility in Randburg, is addressing the problems of storing medication at the correct temperature during power outages.

Conclusion

Another advantage of hydrogen fuel cells is that they have no working mechanical parts, require little or no maintenance while 'up and running', and have a considerably longer life-cycle than other forms of back-up power.

Currently the cost per kW/hour of a hydrogen fuel cell system is not directly comparable with generated power. However, the ease of installation, reliability and low level of support required enable fuel cell systems to provide viable back-up to specific critical applications and in remote locations.

Fuel cell technology is dependent on an efficient, cost-effective mode of hydrogen supply and distribution. The company represented by the author is committed to working alongside other stakeholders to develop a hydrogen distribution solution that is both scalable and economical for the end-user.

Using fuel cells for back-up power in remote, disadvantaged and unindustrialised areas is just the start. As leaders in hydrogen-based technologies, we look forward to forging new partnerships and finding innovative ways of scaling up the technology, using our initial projects as basis.

Not only does the technology address the numerous socio-economic challenges we have in this country, but it points to a more energy-efficient future, which is in line with the global drive to reduce carbon emissions.

Chapter 2

Energy management

What gets measured, gets done. When energy was cheap, we did not care how much we used. Those days are gone. In any plant, process or system, we must be absolutely certain of how much is used, where it is used, and when it is used. Frankly, we all need the skills to measure and verify energy usage. Local capacity to train and educate in this space is well established.

2

Determining energy savings Then and now

I Bosman and Y de Lange, Energy Training Foundation

During the early 90s reluctance to invest in energy efficiency projects was the norm owing to the high uncertainty associated with the determination of the energy savings. This arose largely from inconsistencies in the way energy savings Measurement and Verification (M&V) was applied and the different levels of understanding of the topic.

An initiative to develop an M&V protocol that would help determine energy savings from energy efficiency projects in a consistent and reliable manner was started by a group of volunteers in America. One of the larger goals of this initiative was to help create a secondary market for energy efficiency investments by developing a consistent set of M&V options that could be applied to a range of energy efficiency measures in a uniform manner resulting in reliable savings over the term of the project. Today, the Efficiency Valuation Organisation (EVO)-owned International Performance Measurement and Verification Protocol (IPMVP) is the leading international standard in M&V protocols. IPMVP has been translated into 10 languages and is used in more than 40 countries. Five thousand copies are ordered or downloaded annually [1].

South Africa took the lead in developing an M&V standard to measure energy savings and released the SANS/SABS 50010:2011 [2] almost concurrent with the release of the ISO 50010:2011 [3]. M&V experience was gained in South Africa because of the Eskom Demand Side Management (DSM) initiative, which spurred the development of methodologies to determine energy savings accurately and transparently with the ability to be repeated and compared.

Need for M&V

M&V is seen as an additional discipline in the energy efficiency industry and most certainly has appeal with regard to new business opportunities. The benefit and real value of M&V is not yet clearly understood in industry but rather seen as an 'additional' cost.

The central purpose of M&V is to verify the energy savings achieved either to satisfy internal financial accounting and reporting requirements, or to meet the terms of third-party contracts for project implementation and management.

In South Africa, M&V carried out in accordance with the SANS 50 010:2011 [2] standard is a requirement for energy efficiency tax rebates, and will most probably be the standard used to determine carbon emission tax reduction for energy efficiency initiatives as the greatest contributor to carbon emissions is the generation and use of energy. The IPMVP lists the benefits of M&V as:

- Increases savings
- Encourages better project engineering
- Demonstrates and captures the value of reduced emissions from energy efficiency and renewable energy investments
- Helps organisations promote and achieve resource efficiency and environmental objectives
- Reduces the cost of financing projects by:
  - Providing assurance of Return-On-Investment (ROI) on energy savings projects
  - Increasing confidence of funders that investment debts can be repaid by the savings
  - Reducing the risks associated with the investment

Proven methodology

The IPMVP methodology's statistical principles used are the same regardless of the purpose of the analysis. In principle, M&V simply quantifies energy savings by comparing consumption before and after the retrofit where the 'before' case is defined as the 'baseline performance', and the 'after' case is referred to as the 'post-installation period' [2]. In its simplest form:

$$\text{Savings} = (\text{Baseline Energy Use})_{ADJUSTED} - (\text{Post-installation energy use})$$

The factors that complicate energy savings determination include the way a baseline is determined, the adjustments that apply, how these adjustments are carried out, what measurements are required to determine post-installation performance, etc. and to remember that many factors that can be controlled, or not controlled, influence energy use and alter the baseline requirements. Cases in point are weather changes, occupancy patterns in a building, operating hours, production volumes, space conditions, equipment malfunction, space use changes, tariff changes, etc. These all affect true energy savings reflected and cannot be determined by the simple comparison of this month or year's energy bill, to that of the previous month or year. Energy savings measurement has evolved over the past number of years to take account of all such factors through the IPMVP methodology carried out in a specific framework to ensure quality compliance and control of the M&V process.

Starting the M&V process

Two important decisions need to be made before the M&V process can start:

- Which M&V option as per the IPMVP must be chosen
- The baseline definition for the option chosen (guided by what drives the energy consumption)

M&V options

IPMVP provides four options to the M&V process that can be chosen: Options A, B, C and D and they differ from each other in terms of the degree to which the retrofit can be measured separately from other facility components and the extent to which performance variables

can be measured [4]. Performance and operations factors are taken into account and these are factors that indicate equipment or system performance characteristics such as kW/t, or W/fixture, for example, while operating factors indicate equipment or system operating characteristics such as hours of operation.

Option A: Stipulated and measured factors

The performance and operation factors are based on a combination of measured and stipulated factors, for example, measurements can be taken as spot measurements or short-term measurements at the component or system level. Data can be used from rating plates of suppliers and manufacturers, or the components' historical data. The cost of M&V would be dependent on the number of points measured, and an estimated range could be between 1 and 3% of the energy savings of the project.

Option B: Measured factors (retrofit isolation)

As with IPMVP Option A, spot or short-term measurements at component or system level are used where variations in factors are not expected. Option B applies to a retrofit or system where the measurements can be taken separately from other measures or performance factors. No factors are stipulated in this option but it involves the need for more end-use metering than Option A, which makes it both more expensive and less subject to uncertainty. An estimate of 3 - 15% of the energy savings of the project has been cited [4].

Option C: Utility billing data analysis (whole facility)

With Option C the complexity of the whole building analysis determines the cost which could be in the region of 1 - 10% of the energy savings of the project.

This option applies to the impact of a 'bundle' of retrofit measures on a whole building or facility. Option C relies on total building energy performance data obtained from metering at the point of entry to the facility, from baseline period to post-installation of the retrofit. A requirement is to utilise regression analysis so that performance variables can be accounted for, such as the weather, production and occupancy, etc. to ensure the correct baseline adjustments.

Option D: Calibrated computer simulation (greenfields-type projects)

Computer simulation models of component or whole-system energy consumption are used to determine the projected energy savings. The simulation inputs are linked to the baseline and post-installation conditions, or performance metering before and after the retrofit. The simulation models can be calibrated by using whole-building long-term energy use data from an existing building. As a guideline we suggest the following when making a decision as to which option to use:

- Look at the total project cost
- Then at the expected savings to evaluate the ROI
- Consider the complexity of adjustments required (derived from the complexity to measure and model the drivers)
- The cost of the type of measurement requirements related to the option
- The anticipated changes to post-implementation usage patterns or drivers
- The risks that have to be taken on by the stakeholders
- The uncertainties that need to be determined

Most importantly, choose the least complex method even if it means realigning the project boundaries to be more cost-effective whilst maintaining the least uncertainties that need to be determined.

Baseline

For each option, and for each specific project, agreement between all stakeholders must be reached on the baseline definition (and M&V plan) as it involves, quantifying energy consumption data whilst specifying the factors that affect the energy consumption, taking into account agreed upon variables.

To determine a baseline energy consumption data is required, such as meter readings of bill information relating to the electricity consumption, fuel or water consumption, or any other energy sources data, like steam or even renewables. The variable data that could be required are weather factors, looking at Heating and Cooling Degree Days (HDD or CDD), operating hours of the facility, production, systems for heating and cooling, equipment malfunctions, etc.

Of great importance is the agreement between stakeholders of the baseline adjustments (and how these will be measured before implementation and inferred after implementation) as this forms the fundamental relationship for savings verification of the baseline performance.

This is the most difficult aspect of savings verification to quantify and becomes a contentious issue, which is why it is important to use the services of an experienced M&V consultant. It is not an aspect that can be taught by the book, and includes continuous observation and practice to understand the unknown factors. Correct baseline adjustments level the playing field when determining post-installation performance in relation to the adjusted baseline energy performance – getting this correct adds tremendously to the credibility of the savings expressed at the end of the M&V process.

However, the extent to which baseline adjustments need to be considered depends on the M&V Option chosen. Taken from the Energy Training Foundation's training syllabus [4] the following are examples of baseline adjustments:

- **Changes in weather or occupancy**
  Adjustments might include recalculating the baseline consumption rates using post-installation period weather data or occupancy data based on a mathematical expression of how energy consumption depends on factors such as HDD, CDD and occupancy. The impact of HDD and CDD can be significant and is a topic for separate discussion
- **Changes in operating schedules or tenant improvements**
  The real impact of the retrofit project will be affected by a decrease or increase in operating hours of the facility or the system. Therefore, the baseline consumption needs to be scaled up or down to correspond to such changes, if any. A tenant might also implement its own improvements that may alter energy consumption in the post-installation period such as new lights, or additional plug loads, which are unrelated to the M&V scope determined and must be separated from the post-installation period performance
- **Changes in the actual function of the facility**
  Changes in the use of the facility, for example, converting office space to a store room, affect the baseline performance and an adjustment is required

Establishing a framework for M&V success

Following a step-by-step approach as determined by IPMVP will ensure a continuous plan-do-check-act-type of system as with any implemented management system.

Preparing the organisation

Starting with energy awareness amongst the organisation's staff, from top to bottom, is all-important as they are the key players using the facility to be M&V'ed and influence the energy use. We recommend combining the M&V programme with an energy management system that aligns all the stakeholders and their roles and responsibilities within the requirements of assurance of energy savings determinations.

Select implementation method and process

All stakeholders involved in the M&V programme need to agree on the defined method and process to be used and followed, thereby also identifying M&V roles and responsibilities, timeframes and contractual agreements.

Energy Conservation Measures (ECMs) identification, selection and assessment

A detailed energy audit will identify opportunities for energy conservation as well as Energy Management Opportunities (EMOs).

Design energy savings programme

After the audit, a detailed energy savings plan can be designed incorporating the aspect of M&V – aligning the M&V programme implementation with that of an ISO energy management system provides an even better framework for a successful M&V programme.

M&V planning preparation

Before implementing any energy savings project, the following sub-steps must be followed to ensure alignment with the M&V requirements:

- The IPMVP option must be selected
- The base year of performance must be defined i.e. which is the year that will be used as the basis against which energy performance will be measured post-implementation
- Define the post-implementation period for the ECM, which is the period that will be compared with the base year period so that the project impact can be measured
- Develop the M&V performance model in line with the IPMVP, which includes the selection of data analysis techniques, algorithms, equations and establishing assumptions, etc
- Testing the M&V performance model to check what changes and adaptations are appropriate. The impact of the expected accuracy and uncertainties are quantified and their impact on the cost-effectiveness of the programme

Metering

Metering considerations must be defined and specified in accordance with the IPMVP option chosen and include aspects such as metering points, frequency and duration of metering, type of meter and its required precision and calibration requirements, etc.

M&V's continuous management

For quality assurance, the M&V's continuous management of its programme needs to be defined; the roles and responsibilities and reporting systems must be in place.

Documentation

During the M&V programme and its framework development attention need to be paid to documenting all the relevant decisions in the planning and management system – this forms the basis for all M&V activities. Implementing an ISO energy management system concurrently sets out a structure for the required documentation automatically.

Implementation of ECM in parallel with the M&V plan

The M&V plan forms an integral part of implementing the ECM and should be formulated in parallel to enhance the assurance of the reported energy savings post-implementation.

Conclusion

Although M&V experience is fairly thinly spread in the South African workforce, the M&V skills in South Africa are of the most advanced in the world. A small group of well-oiled true M&V personnel exists in this industry to have ample experience to share knowledge and assist companies with achieving the financial assurance in energy savings projects and initiatives required to reduce their investment risks.

The Energy Training Foundation (EnTF) has been training Certified Measurement & Verification Professionals (CMVP) since 2006 under licence to the Efficiency Valuation Organisation (EVO) and under Association of Energy Engineers (AEE) licence and is the sole training provider for this internationally recognised qualification in the Southern African region.

M&V Professionals with the CMVP qualifications have obtained these by being trained in the industry and by passing stringent examination requirements. They also have to have a minimum of three years' experience to carry the title of a CMVP – in addition, renewal of this status is required every three years as one cannot claim to be professionally accredited without continuously keeping up to date.

Implementing an effective M&V programme is like implementing an ISO-aligned quality management system or energy management system alike.

Once again, you cannot manage what you do not measure and a well-managed M&V programme will deliver measured results on a continuous basis; the ultimate surety to project viability. Implementing an ISO energy management system in parallel with an M&V programme will enhance assurance whilst providing opportunity for even better continuous management of energy use, delivering benefits year-on-year.

The M&V industry and its evolution is only in its infancy at this stage in the world – not only in South Africa - with many more opportunities for its use being identified regularly. The sooner you start with M&V the better your chances of getting new budget for new energy saving projects.

References

[1] EVO-world.org. The History of the IPMVP. August 2015.

[2] SANS/SABS 50010. 2011. Measurement and Verification of energy savings.

[3] ISO 50010. 2011. Energy management standard: Energy monitoring.

[4] Energy Training Foundation material. Energy auditor training. Module 10: Verify energy savings.

An industry that is competitive is an energy efficient industry. Energy efficiency is no longer simply efficient devices – it entails understanding your system, the way it operates, and how it can be optimised to be efficient. This implies a rethink of how we do business, and it involves all the people in your organisation. They are part of the system.

2

Changing the organogram for optimal energy management

Y de Lange, Energy Training Foundation

What is interesting to note from the Ernst & Young survey quoted (see page 35) is that, globally, organisations are indicating that a formalised energy efficiency programme through an energy management system is the way to go, ahead of many of the other solutions mooted, such as generating your own power. The energy management system will optimise energy efficiency programmes through ensuring that proper skills and expertise can drive them towards sustained competitiveness in your industry, on top of saving energy.

What is energy efficiency?

The word energy efficiency is so often used - and confused: Simply purchasing the latest and greatest technology does not mean you are energy efficient.

The general definition for energy efficiency is understood as the system boundary that lies between your energy input and your useful work output (see *Figure 1*). It is similar to managing a bank account. The budget is the financial boundary that lies between your deposits and your expenses. Within the budget is where you control that optimised use of your cash. View energy efficiency in the same way.

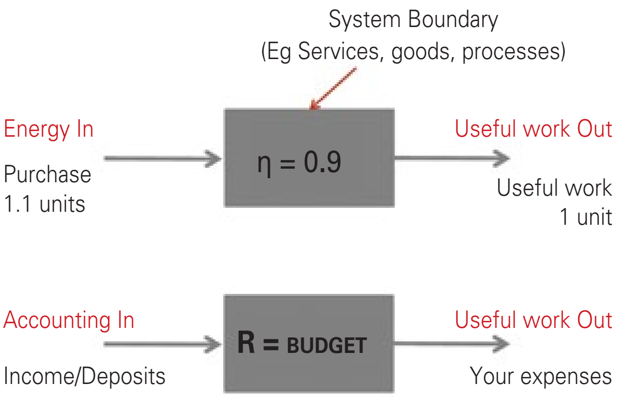

Figure 1: Energy management system verses an accounting system – do you run a business without an accounting system?

In many instances, South African organisations that embark on energy efficiency purchase technologies and equipment before ensuring that there is a department that understands how to define an approach (energy boundary or budget) to work within the boundary of the system. Only when an energy management system is in place can a decision be made regarding what is required to ensure the optimal performance of any investments, including technological investments.

This is how the energy industry is changing – finance and carbon tax reductions, deductions and even investment financing will eventually only be granted to those with an energy management system. Engineers cannot hold accountants responsible for not investing in energy efficiency without knowing that their investment is securely managed.

Why is energy efficiency internationally supported as the preferred solution?

As regularly reported in respected journals, saving energy should be approached in a constructive manner so that the system boundary 'spending and wasting' can be controlled by following the first steps (see *Figure 2*).

- ***Behavioural change:*** Up to 30% savings – this would require minimal investment which could include continuous communication, awareness and training at all levels within the organisation
- ***Operational efficiency:*** Between 10 - 40% savings – merely identifying problem and energy waste areas and implementing and managing corrective measures could require minimal investment if managed by a trained professional
- ***Equipment efficiency:*** Between 5 - 10% savings – merely identifying opportunities to improve efficiency of existing equipment and implementing and managing this could require minimal investment if managed by a trained professional
- ***Technology changes:*** Up to 60% savings – major investment opportunities could be identified for these types of savings. However, if it is not implemented and managed continuously by a trained professional the ROI won't be maximised and the savings might be short-lived

The golden thread is the importance of managing the processes through a trained professional as the options that need to be explored can become complex, and the calculations to ensure the energy savings remain and improve need to be acquired and practised.

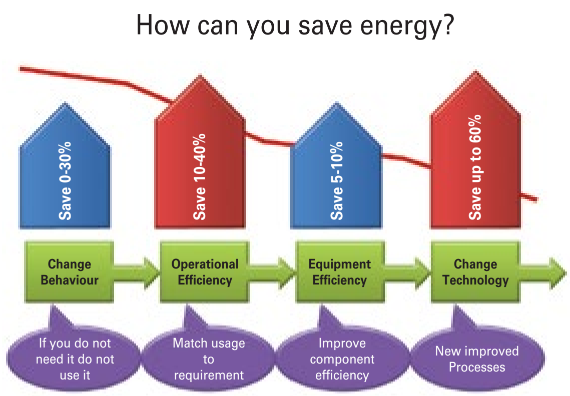

Figure 2: The potential for energy saving, courtesy under licence to the EnTF from the AEE CEM.

In a recent survey undertaken by Ernst and Young (E&Y) [1], almost 40% of large corporations in the world see energy costs rising over the next five years, with expected increases of at least 15%. In South Africa, the National Energy Regulator (NERSA) is continuously faced with applications by Eskom for similar increases as is globally expected. However, for us it is annual increases and will amount to more than five times what is globally expected.

The E&Y survey indicates that 92% of respondents view energy saving as the primary objective that major corporations strive towards to contain the anticipated increases and become more competitive. An overwhelming majority has a formal strategy implemented with 82% indicating that energy efficiency programmes will be increased during the next five years. If this survey's findings ring true - that international organisations are reacting aggressively towards curbing a mere 15% increase over five years through energy savings - it should ring warning bells with a 15%+ increase looming annually over the next five years for South Africa.

Are we moving in a similar direction? What are our priorities compared to those of the international organisations? Is energy efficiency, through committed energy strategies and management programmes, and human resources, at the top of our boardroom agenda?

International trend

Prioritising energy efficiency and employee education seems to be a main component of international organisations' energy policies. The Association of Energy Engineers (AEE) conducted a survey of the energy industry [2] where almost 80% of respondents have set goals within energy management policies that need to be attained. Although most of the organisations indicated that they have, as part of their policy, the implementation of renewable and alternative energies, the leading component prioritised, by far, was energy efficiency, which ranked 87% on the list, with employee education to reach the targets in second position at 67,4%, and environmental impact coming in at 62,3% as a third priority.

In another AEE survey on the Green Jobs [3] in the world, indications were clear that within these management plans specialist human resource skills are a given – with permanent positions in energy management departments to ensure the sustainability of the energy plans. Within the organograms, the titles of project manager and energy consultant seem to make up 50% of the job descriptions, with about 24% carrying the title of energy manager and the remainder shared between utility account managers, facility managers, contractors, energy executives and energy services companies as an outsourced service.

Even during tough economic times, globally the survey [3] indicates that about 64% of companies are maintaining their energy management staffing levels, whilst just over 28% of these companies are adding to their staff complement, with the balance making staff reductions. The reason given: During the recession years recently experienced, and being experienced globally, the 'cleantech' segments of the energy economy outperformed the national economy as a whole. Rising threats of increases make it more pertinent to remain competitive by using resources more 'resourcefully'.

South African context

Managing and measuring energy is like managing and measuring a commodity that you cannot see, which makes it a complex task that needs specialised skills. However, in South African energy management departments, although many energy managers have been trained in South Africa, these positions mostly form a secondary level of commitment to such a person's main job function. The main job functions are found to be quite demanding in most instances, like running a plant or an engineering and maintenance department. Where there is an energy manager appointed within an organisation with energy management as the main function, the tendency is to add another secondary portfolio which is just as demanding.

Most South African energy managers do not have a team to assist. Where there is a team, managing energy is an item on a list of activities of the team members owing to the multi-skilling culture that exists in South Africa. This trend does not collaborate with the international action taken to ensure competitive development through energy efficiency and continuing with such practice is in contradiction to what is international best practice.

Aligning human resources with ISO 50 001 and international trends

The internationally tried and tested energy management systems have been captured for international use in the ISO 50 001:2011 – the standard for Energy Management Systems [4].

ISO 50 001 [4] is based on the Plan Do Check Act (PDCA) continual improvement framework and incorporates energy management into everyday organisational practices. ISO is the point at which all companies should start when considering energy savings projects, even before considering generating your own electricity through renewables. It is the first step to safeguarding that, when the energy efficiency road is taken, it is within a controlled 'budget' to ensure its success. However, to ensure it remains part of everyday organisational practice the appropriately qualified and trained human resources need to be in place.

ISO requires that energy management is implemented and reviewed by Top Management – it is where the commitment to support and continually improve the effectiveness is required. Top management is defined as: A person or a group of people who directs and controls an organisation at the highest level.

It is top management's responsibility to embrace the responsibility of drawing up an energy policy to build a sustainable energy management system and regular review is required to close the responsibility loop. Top management is steered through ISO to appoint a management representative with the appropriate skills and competence, as well as an energy management team. Resources must be provided that include human resources, specialised skills, as well as technology and financial resources. A person should be qualified and experienced in effectively executing tasks like:

- Identifying energy savings opportunities through energy auditing or energy use measurement data, and/or be able to interpret the results of the data presented from an energy audit
- Conducting and documenting an energy planning process and an energy action plan
- Being able to understand the organisation's holistic operations and production processes and challenges
- Being knowledgeable about the legal and other requirements that are affected by implementing energy projects and energy saving interventions
- Implementing an energy baseline and the consequent baseline adjustments to ensure continuous energy savings are strived for

- Being aware that it is necessary to compare the progress of the energy savings projects and initiatives with that done in other similar industries through benchmarking

Top management is responsible for ensuring that staff attain and maintain the required competence levels, and records must be kept, especially when ISO 50 001 [4] certification is pursued.

Training and education for effective energy management

There are many training providers out there grappling at educating within this topic. The AEE has been in existence for 37 years, and its Certification programs are accepted in 90 countries. Its flagship qualification, Certified Energy Manager (CEM), is accepted – and in some instances a prerequisite – by international governmental departments, regulatory requirements, human resource agencies, etc [5]. In South Africa a similar trend is trailing where preference is given to CEMs for energy management positions within energy intensive organisations, and those with serious energy and environmental policies in place. Over 16 000 professionals are certified world-wide by the AEE in the various energy engineering disciplines. Within South Africa the AEE has trained, through its approved trainer the Energy Training Foundation (EnTF), 1 475 CEMs and in the other disciplines another 650. Most of the energy intensive industries already have CEMs within their organisations.

The Certification programme works on a similar basis to the Engineering Council of South Africa (ECSA) registration of Professional Engineers, Technologists and Technicians. Certified AEE professionals are required to demonstrate Continuing Professional Competency (CPC) by apprising themselves of the latest industry trends and technologies.

Eligibility for AEE Certification carries certain minimum requirements and takes into account the possible diversity of education and practical experience an individual may have.

Once the examination is passed, a candidate can apply to the international board for certification, with additional related degrees and experience necessary.

The strict requirements ensure that once Certification is awarded and maintained, a person is recognised being part of a distinguished group of international professionals.

Availability of energy engineering skills

The shortage of skills in the energy engineering industry holds similar proportions to other specialised careers. The Green Jobs Survey [4] indicates that almost 70% of respondents believe that there is a shortage of professionalised skills in energy management and energy efficiency, and most of these believe this will remain the case in the next five years. This is mainly due to the fact that certification, done right, requires primary education in another profession, followed by years of experience, before adequate contributions can be recognised by the AEE – an extended experiential timeline before recognition is granted.

That being said, 50% of the AEE Certified professionals that responded to the survey [3] indicated that they had gained a competitive edge towards better positions and career advancement; 80% of the respondents had experienced greater career improvement and significant benefits to the companies they worked for, or provided services to.

For the Southern African region the AEE provides opportunities for persons aspiring to attain the educational background and related recognition through its sole regional training provider, the Energy Training Foundation (EnTF).

Conclusion

Optimal energy management will be more in reach when human resources are aligned with an energy management system and strategy. This will lay a sound foundation for sustainable business and economic growth, whilst reducing the negative impact on the environment as a whole.

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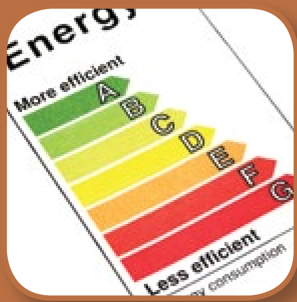

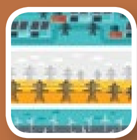

Chapter 3

Energy savings in industry

Heat intensive processes require large amounts of energy – they also offer many opportunities for improvement. The overall system must be evaluated and understood in order to optimise the energy usage and evaluate the real benefit. If done properly, not only will the process itself not be compromised, it may even be improved in terms of the quality of the final product.

Novel processes for Food and Beverage Quality, safety, efficiency

A Murray, consultant

Most of the conventional processes used for the pasteurisation and sterilisation of food products depend on the application of heat. Today, there are a number of innovative processes that cause less damage to the food. Some of these processes make better use of energy and are less easily affected by interruptions in power supplies than conventional processes.

The aim of the food processing industry is to produce safe wholesome food from specified raw materials. Control of pathogenic and spoilage microorganisms has traditionally been achieved by thermal pasteurisation and sterilisation, by chilling and freezing, by reduction of the water activity in the product and by means of chemical preservatives.

These processes need to take place in an hygienic environment. Most often the use of heat together with the application of cleaning chemicals and sanitisers provides for sanitation of both the process equipment and its surroundings.

Pasteurisation, sterilisation, sanitisation

The source of heat for pasteurisation, sterilisation and sanitising operations is usually derived from steam. Steam generated from the combustion of fossil fuels accounts for over 50% of all the energy used in the food industry.

A number of innovative pasteurisation, sterilisation and sanitising processes have been researched over the past few decades. Some of these have been commercialised. Many of the novel processes that are employed in the industry have been developed to ensure less heat damage to the food. This results in products with a fresher, more natural taste. The energy considerations that were secondary in the development of the processes are now becoming a consideration. The energy engineer needs to be aware of the implications of these novel processes.

The advent of large scale load shedding in South Africa has brought into focus the vulnerability of the food industry. Power cuts of even very short duration can result in breaking the integrity of the process. This may then require recycle or disposal of the product within the process and the necessity to re-sterilise the equipment. In cases where indirect steam heating is used there may be burn-on of sensitive product to the surfaces of the heat exchanger. Cleaning and sterilisation are then required. Most of the innovative processes are less prone to the risks of product damage at times of power failures.

Pasteurisation technology

Pasteurisation of beverages may be achieved prior to bottling (so called flash pasteurisation) or after sealing in the bottle (tunnel pasteurisation). Flash pasteurisation typically takes place in a three section plate heat exchanger, with heating coming first by the use of the regenerative heat from the exiting product and then from hot water in circulation. In the third section of the exchanger the outgoing pasteurised product is cooled. This process requires that filling and capping take place in an enclosed sanitised area to prevent reinfection. Heating requirements for pasteurisation vary considerably. A typical flash pasteurisation process for milk or fruit juice generally requires between 30 and 120 kJ per kg of product.

Tunnel pasteurisation is a process where the filled beverage product is pasteurised in the bottle (bottles in this article may also refer to cans or pouches in certain instances). Bottles on a conveyer belt move through different temperature zones where heating and cooling take place.

Filling and capping operations do not require such stringent sanitising as for flash pasteurisation processes. Tunnel pasteurisation is safer. While the regeneration in a modern flash pasteuriser exceeds 90%, in a tunnel pasteuriser only 60 or 70% is likely. The energy requirement could thus be three or four times as much for the tunnel pasteuriser as for the flash pasteuriser.

Novel pasteurisation and sterilisation processes

Innovative pasteurisation processes may be divided into those where the micro-organism control is achieved through non thermal processes and those where a novel method of heating is used. Four novel processes are considered:

- Pulsed electric field
- Ultraviolet pasteurisation
- Ultra high pressure processing and
- Induction heating

These are by no means the only innovations in this industry. For instance, filtration and centrifugation are being used widely for reducing the microbiological load in products where extended shelf life is required.

Pulsed Electric Field (PEF) technology

In this process, pulses of high voltage (typically 20 - 80 kV/cm) are applied to foods placed between two electrodes. Usually this is at temperatures around ambient and for times of less than one second. PEF technology has found application in the pasteurisation of fruit juices, particularly in smaller capacity units. Powering smaller capacity PEF units by PV solar in rural areas has been suggested. The power requirement is approximately 100kJ per kg making it no more economical in terms of energy than conventional pasteurisation. Longer run times are however possible due to a lack of fouling providing for some economy.

Ultraviolet light pasteurisation (UV)

Ultraviolet processing involves the use of radiation from the ultraviolet region of the electromagnetic spectrum for purposes of disinfection. Typically, a wavelength of 100 to 400 nm is used. The germicidal properties of UV irradiation are mainly due to DNA mutations induced through absorption of UV light by DNA molecules. UV light does not penetrate opaque liquids such as milk. However, the use of high turbulence and the correct positioning of lamps makes it possible to reach the entire volume of liquid. In this way UV treatment, which was previously limited to clear liquids such as water and wine, may now be applied to fruit juices and milk. The latter requires regulatory approval. The power requirement is as low as 10 kJ per kg, making it an attractive process from an energy efficiency point of view.

High Pressure Processing

High Pressure Processing (HPP), also described as High Hydrostatic Pressure (HHP), or Ultra High Pressure (UHP) processing, subjects liquid and solid foods, with or without packaging, to pressures between 100 and 800 Mpa. The application of the pressure may be pulsed. Treatment times vary between milliseconds and 20 minutes. The cost of the process is high owing to the cost of the containers that will withstand the pressure. Despite the high cost commercial applications for HPP cover a wide range of products. Energy requirements should typically be 20 to 30 KJ/kg processed.

Induction heating

In inductive heating, electric coils placed near the food product generate oscillating electromagnetic fields that send electric currents through the food, primarily to heat it. Such fields may be generated in various ways, including the use of the flowing food material as the secondary coil of a transformer. Commercial applications of this process include the sterilisation of milk at temperatures above 140°C and the pasteurisation of liquid egg. Tubular modules are used for these operations. Because this is a heating process the energy requirements would appear to be similar to those of conventional pasteurisers. Heat transfer coefficients, however, are higher leading to shorter warm up times and little heat is retained in the machine after switching off, thus alleviating the problem of burn-on on heating surfaces.

Sanitation processes

Traditionally sanitation in the food industry is achieved by heat and by the use of chemical sanitisers. The use of Ozone (O_3) and Electrochemically Activated (ECA) water are relatively recent innovations that allow sanitation using compounds that are transient and will thus not have any long term effects on the food products.

Because of its relatively short half-life, ozone is always generated through corona-discharge. It is widely used in the food and beverage industries both in gaseous form and dissolved in water. Sanitation of cold room spaces and the rinsing of bottles prior to filling are typical applications.

ECA water is produced by a process which converts tap water or salt water into two products:

- Anolyte which is used as a disinfectant
- Catholyte which is used as a detergent

The process is similar to the salt chlorinators used in swimming pools. ECA is also finding wide use within the food industry.

Energy – the whole process

It is important that the energy analysis of novel or innovative processes is not taken in isolation but incorporated into the factory design as a whole. An example of energy analysis needing to be holistic is in the comparison of flash and tunnel pasteurisation for carbonated beverages. A large flash pasteuriser may require approximately 30 kJ/kg product energy input whereas a tunnel pasteuriser will consume 130 kJ/kg on the same process. However, if the product is bottled cold, as it would be in the case of carbonated beverages, then condensation on the bottles post filling will need to be prevented. The heaters required to do this will require approximately 105 kJ per kg. If the cold water produced in the warming cannot be utilised elsewhere in the factory then the flash pasteuriser, which initially looks to be much more efficient, will not produce any energy savings.

Conclusion

Many of the innovative pasteurisation, sterilisation and sanitation processes that have recently been developed in the food industry can be used to improve the quality of foods and beverages. There are possible reductions in energy requirements when these processes are used. However, they need to be analysed holistically.

Definitions

- **Pasteurisation** is a process designed to control pathogenic organisms and some spoilage organisms
- **Sterilisation**, a more severe process than pasteurisation, is designed for the control of all pathogenic and spoilage organisms

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Copper is synonymous with electric energy. This special metal is more than just 'a good conductor of electricity'. Theft of copper has become a national sport and no review of energy can avoid 'the elephant in the room': How are we doing in reducing the costs and damage associated with copper theft?

Today's industry harmed by copper theft

E Swanepoel, Copper Development Association Africa (CDAA)

The theft of ferrous and non-ferrous metals, particularly copper, has increased drastically in recent times. Its place in a discussion on energy efficiency is appropriate as the scale of theft has escalated beyond imagination causing crippling power outages throughout the country, harming business, industry and lives.

It is estimated that copper theft – regarded a 'high priority crime' – costs the South African economy about R5 billion every year. It affects everyone. South Africa's Minister of Energy would like copper theft to be classified as economic sabotage.

There are well-organised criminal syndicates operating throughout South Africa that are crippling this country's economy. These syndicates have international links and influence, including disturbing relationships with scrupulous scrap metal dealers and exporters.

Copper thieves have developed several techniques over the years and are becoming increasingly violent. The fact that electrical network theft is extremely dangerous and fatalities are a regular occurrence has not hampered their efforts. Syndicates target the poor and desperate to entice them to carry out the dangerous work while the syndicate members only come into the picture after the fact. The thieves employ 'Heath Robinson' type contraptions to steal copper-bearing cable. Long trenches are dug in a very short time to access and steal underground cable; and simple objects, such as wooden poles, are used to 'trip' the power so that organised gangs can steal overhead cables, causing severe damage to electrical networks.

Government intervention

The South African government has instigated a number of measures to curb criminal activities in the ferrous and non-ferrous markets and clamp down on the illegal trade of scrap metal. These measures include the recent amendments to the Second Hand Goods Act and the Export Regulations. The amendments take into account instances where copper cable has been burnt or altered. The general purpose of tightening the export regulations is to retain high quality scrap metal within the South African economy and to prevent the export of stolen scrap metal. In principle, these amendments will help but enforcement and monitoring remain challenging.

There are legal disposal contractors who have been appointed to buy redundant copper from municipalities and other utilities. They are there to regulate the processing of the material and to prevent it from entering the market but there are many illegal operators who buy copper.

CCTV surveillance videos exist of scrap copper being delivered by workers driving an electrical contractor's company vehicle to an illegal metal trader operating locally. The video footage shows the vehicle entering the back of a bottle store's premises – the 'front' for the illegal metal trader's operation – and the workers unloading copper cable. This video footage proves that every electrical contractor is vulnerable: employees steal cable and sell it to an illegal trader, implicating the contractor, who may find himself being arrested and having to explain the stolen cable to the police. Substantial rewards are offered for related information.

South African Chamber of Commerce and Industry (Sacci)

Copper theft barometer: April 2014

The Sacci Copper Theft Barometer for 2014 increased to R12,5 M in April from R11 M in March and R10,7 M in February. The April figure is 26% higher than a year before and the second consecutive increase in the annual growth rate. Hopefully this upward movement can be arrested through intensification of policing efforts and information-sharing amongst key stakeholders.

Conclusion

Legitimate scrap metal dealers can be particularly helpful in the fight against copper theft by reporting stolen material and not buying any metal they believe may have been stolen. When there is no demand, the supply will also cease.

General awareness of the seriousness of copper theft would be extremely useful, particularly if the awareness is spread through the community to law enforcement and justice departments as this will lead to more severe sentences being imposed by the court, which will ultimately serve as a deterrent.

The Copper Development Association Africa (CDAA) is engaging with government to change the laws controlling the export of copper scrap as the current legislation is totally inadequate. The CDAA is keen to expand the use of copper into Africa. The CDAA would like to partner with government and the mines to pursue the downstream beneficiation of copper and produce copper products to benefit all the people of Africa. The production of copper tops for bedside, over-bed tables, door handles, push plates and Intravenous (IV) stands will also create job opportunities and reduce unemployment.

General discussion

Copper in healthcare

The CDAA is actively working to develop the downstream production of copper items, particularly in the healthcare sector by highlighting the dangers of HAIs (Hospital Acquired Infections) in hospitals and clinics. Thousands of patients die in hospitals every year as a result of infections contracted in healthcare facilities. In future, these deaths

can be avoided by installing antimicrobial copper touch surfaces in hospital wards and ICUs.

Copper in HVAC systems and generators

Air-borne fungal spores can pose problems in buildings, not only in hospital environments where people are susceptible to invasive fungal infections but in any building where air-conditioning units are installed. Increasingly more time, estimated at over 90%, is spent in indoor environments in developed countries and may contribute to sick building syndrome.

The use of aluminium fins within air-conditioning units offers no protection from the spread of fungal spores and may, in fact, increase their numbers. Incorporating copper into HVAC systems in place of aluminium offers the potential for a method of controlling fungal spore growth and survival and thus reduce the risk of infection and spread of fungal related diseases.

Copper has the highest rated thermal and electrical conductivity. Generators with 100% copper windings provide ultimate reliability

and performance. With continued load shedding predicted to continue for at least two years, ensure your standby generator is engineered to perform at optimum. Diesel engine powered electrical generators (diesel gensets) are used for primary power delivery and as a back-up supply that can deliver electrical power in the event of a mains failure. Good reliability, ease of maintenance, and abundance and relative cheapness of fuel mean that diesel generators are a common choice for these applications.

Copper in Aquaculture

The introduction of copper fish cages has tremendous advantages for fish farming. Copper nets antimicrobial/algaecidal properties are anti-biofouling which results in healthier and larger fish. Copper holding nets have strong structural properties, preventing damage from predators.

Acknowledgement

Information on copper theft was provided by Roy Robertson, a former Lieutenant Colonel in the SAPS and principal director at CPI, a corporate investigation firm based in Midrand, Johannesburg, which specialises in the investigation of non-ferrous metal theft. Robertson has been actively fighting copper theft since 2002.

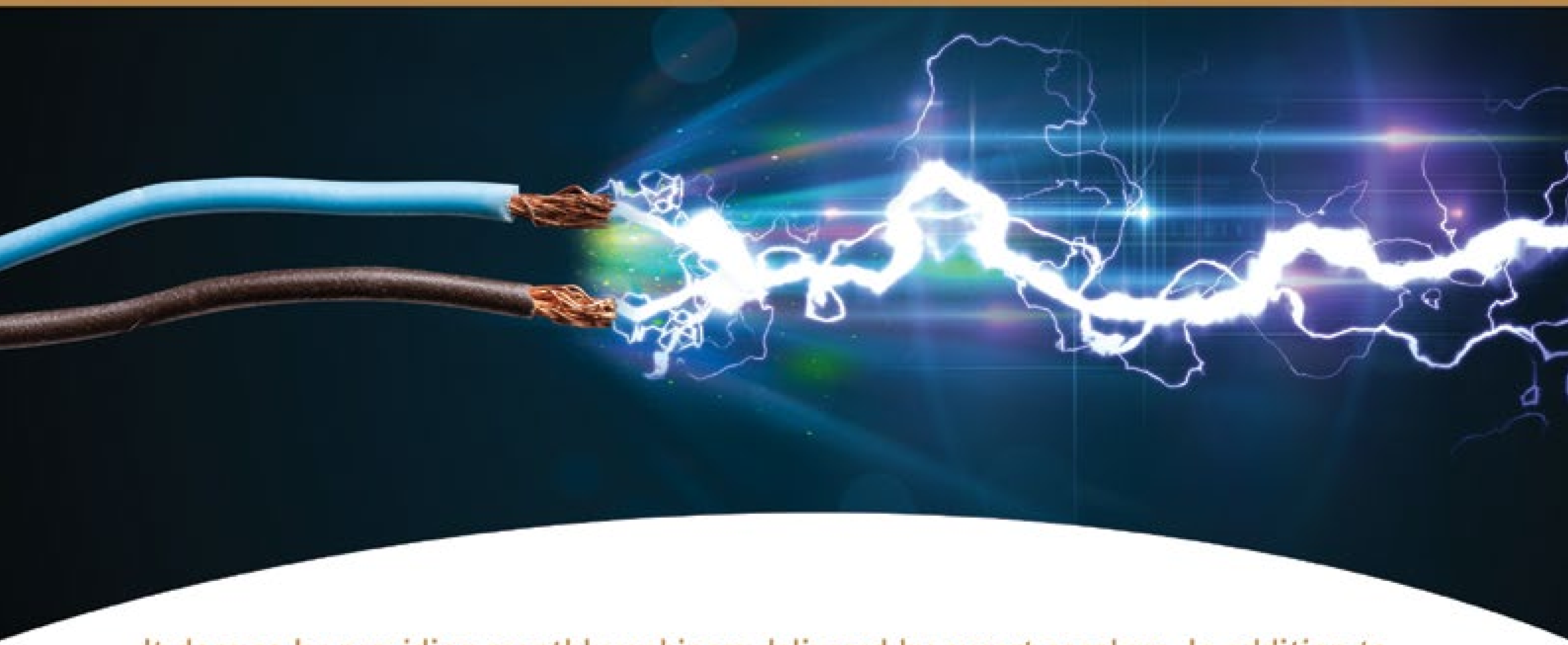
Focusing specifically on the syndicates that target the electrical networks of most electricity supply companies and railway networks, CPI secures and tracks high value cargo, and investigates hijackings and the theft of non-ferrous metals. Operating mainly on intelligence, the company has a staggering success rate. The figures speak for themselves.

In March 2015, the CPI arrested 79 copper cable thieves. Over the past 10 years, the CPI force has recovered millions of Rands worth of copper destined for the export market. In 2005, 34 truckloads, each carrying in the region of 30 to 34 tons of copper, were recovered.

Fact file

- *Chinese copper consumption has increased from 2,8 million tons in 2002 to 8 million tons in 2012 and imports rose from 620 000 tons to 4,4 million tons*
- *The world's copper mines now produce 17 million tons of copper, up from 14,5 million tons a decade ago*
- *In 2005 copper fetched $0,70 per pound, today's price is around $3,15 per pound*
- *The Statue of Liberty contains over 179 200 pounds of copper*
- *Copper is 100% recyclable*
- *Copper retains 95% of its original value and can be re-cycled without any property variations*
- *About 80% of the copper that has ever been produced is still in existence*
- *Despite being less valuable than silver or gold, copper has been dubbed 'Man's Eternal Metal' owing to its versatility and durability*

Leonardo ENERGY Academy promotes lifecycle thinking and best practices asset management for cables.



It does so by providing monthly webinars delivered by expert speakers. In addition to economics and technology, environmental and business aspects are also covered. Power cables are key assets in electricity networks that can have a strong impact on the cost of electricity, but also influence the quality of service experienced by consumers.

Economic Sizing of Power Cables

This programme calculates cable size taking account of type of cable, installation method, circuit length, overload protection, ambient temperature and circuit grouping. Results are presented for the minimum size (ie. BS 7671) and for each incremental size up to the most economic size (ie. IEC 1059). For each size, the overall lifetime cost and the payback period are calculated. The economic calculations take account of load growth, discount rate and increases in energy costs. Cable and installation costs can be modified by the user to suit local conditions.

http://www.leonardo-energy.org/tools-and-tutorials/economic-sizing-power-cables

Power Quality

Power Quality has become a major concern for a large number of industrial sites and buildings. This guide provides an easy reference to the major power quality phenomena, the problems they are causing, and measures to avoid those problems. It is unlikely that a single solution will be effective. Careful design of a solutions mix, tailored to the PQ problems experienced, and based on a detailed understanding of the causes of the PQ problems, is needed.

http://www.leonardo-energy.org/good-practice-guide/introduction-power-quality

Cable Theft

Cable theft has become a national problem that costs South Africa about R5 billion per annum and destroys the country's infrastructure. The CDAA urges you to report copper cable theft to your nearest police station.

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In steam and electrical trace heating, heating energy is required to maintain the temperature of the process product – implying that a reduction in heat lost will reflect in less input energy required. Heat tracing must be factored into any energy saving strategy.

3

Heat tracing technologies – gearing for energy savings

N Liddle, Thermon South Africa

Process heating accounts for about 36% of the total energy used in industrial manufacturing applications [1]. As energy costs continue to rise, industrial plants need to find effective ways to reduce the energy used for process heating. This article discusses the evolvement of Heat Tracing technologies (both electrical and steam) and the role that modern heat trace systems and components play in energy savings.

It is estimated that anywhere up to 85% of the energy supplied to industrial process heating equipment is actually used for heating - the rest being lost due to inefficiencies such as heat losses. Effective heat tracing systems and control methods can assist greatly to minimise heat losses.

What is the purpose of heat tracing?

Heat tracing is a source of external heating to pipes, storage tanks, vessels and instrumentation for the purpose of process temperature maintenance and freeze protection. Simply put… if process fluid temperatures are to remain constant in the process lines, then the amount of heat energy that has to be added must be equal to the amount of heat energy that is being lost from the process fluid.

Maintaining fluids and gases at elevated temperatures reduces viscosity (makes the product easier to pump), enhances combustion (on fuel lines), and prevents freezing or crystallisation where there is a fluctuation in ambient conditions.

Typically in the oil and gas industry, the upstream sector requires elevated temperatures to move the crude oil and raw natural gas to the surface. The downstream sector requires freeze protection to the refining, petrochemical and distribution of the products.

In power generation, heat tracing needs vary from providing winterisation for steam and water lines, to maintaining fly-ash hoppers and 'CEMS' sample lines above the flue gas dew point.

Heat tracing methods - history

Since the early 1900s steam tracing has been the primary means of keeping materials such as petroleum residues, tars and waxes flowing through pipelines and equipment in the petroleum and chemical processing industries.

Following the Second World War, the petroleum and chemical industries grew substantially. Many of the raw materials for these new products had to be maintained at lower temperatures and held within a narrow temperature band to protect the quality of the end product. The 'bare' steam tracing method of the time was frequently inadequate to meet these requirements. Various methods were tried to reduce the amount of heat supplied by the bare tracer. However, unpredictable heat transfer rates, hot spots, and high installation costs were often encountered.

During this era plant engineers were inclined to use fluid tracing methods (glycols and hot oils) where possible because of the ease of regulating fluid flow to maintain required temperatures although, owing to inadequate fittings, leaks frequently presented a problem. Electric resistance heating was also developed in the early years of the 20th century and some types were adapted for pipeline heating, but they had minimal use because of burn out failures caused by excessive sheath temperatures at high wattages. Fittings and connections were also weak points in the system.

In the 1950s experimentation began in earnest to develop more durable electric tracing methods that could be adapted to automatic temperature controls. These efforts brought about marked improvements and by the 1960s, electric tracing began to be accepted as a viable challenger to steam and fluid tracing methods for heating process plant piping and equipment.

Which heat trace technologies are used today?

Surprising to some, steam is still predominantly used for heating energy in approximately 60% of chemical-, petrochemical-, and industrial processing plants.

A typical chemical plant can have around 55 000 metres of steam tracing and a refinery, 220 000 metres of steam tracing – therefore there is considerable scope for improvement and energy savings.

In Africa there are many remote locations with inadequate electricity supply. In South Africa specifically, Eskom is facing capacity constraints, forcing industry to reduce electricity consumption and hence the trend to consider steam tracing.

Industrial steam users contribute to an enormous amount of energy wastage in most countries, with many plants being outdated and in a poor state. It is estimated that in the United States alone, roughly 2 800 trillion Btu of energy could be saved through cost-effective energy efficiency improvements in industrial steam systems [2].

The wastage can be as a result of worn insulation, leaking pumps and valves, etc. Correctly matching the steam tracer type with a heat output that closely matches the heat loss from the process will improve the system's efficiency.

Today, a wide range of steam tracing methods exists. New pre-insulated steam tracers have been developed that offer a range of heat transfer rates for low to medium temperature control as well as improved safety. Where low pressure steam is available, these tracers may be used to heat materials such as caustic soda, resins, acids and water lines, which previously could not be heated with bare steam tracing. Insulated tracers may also be used for temperature control where higher steam pressures are available rather than installing pressure reducing valves.

For the high temperature range, steam may be used as the heat transfer medium in a modern 'conduction' tracing system where heat transfer compound is installed over the tracer and covered with a steel 'strap-on' jacket to provide permanent and maximum contact at the surface of the pipeline.

Heat transfer compounds (also known as 'heat transfer cement') provide efficient thermal connection between tracer and process equipment. By eliminating the air cavities, heat is transferred into the pipe or tank wall through conduction as opposed to convection. A single tracer using the cement has the comparable performance of three to five bare tracers.

Additional benefits of using such compounds include a possible reduction in the number of tracers needed compared to bare tracers, and the ability to replace jacketed pipe without the high cost and fear of cross contamination.

Figure 1 portrays a typical steam tracing system. Most steam tracing is used in 'run free' systems where no control methods

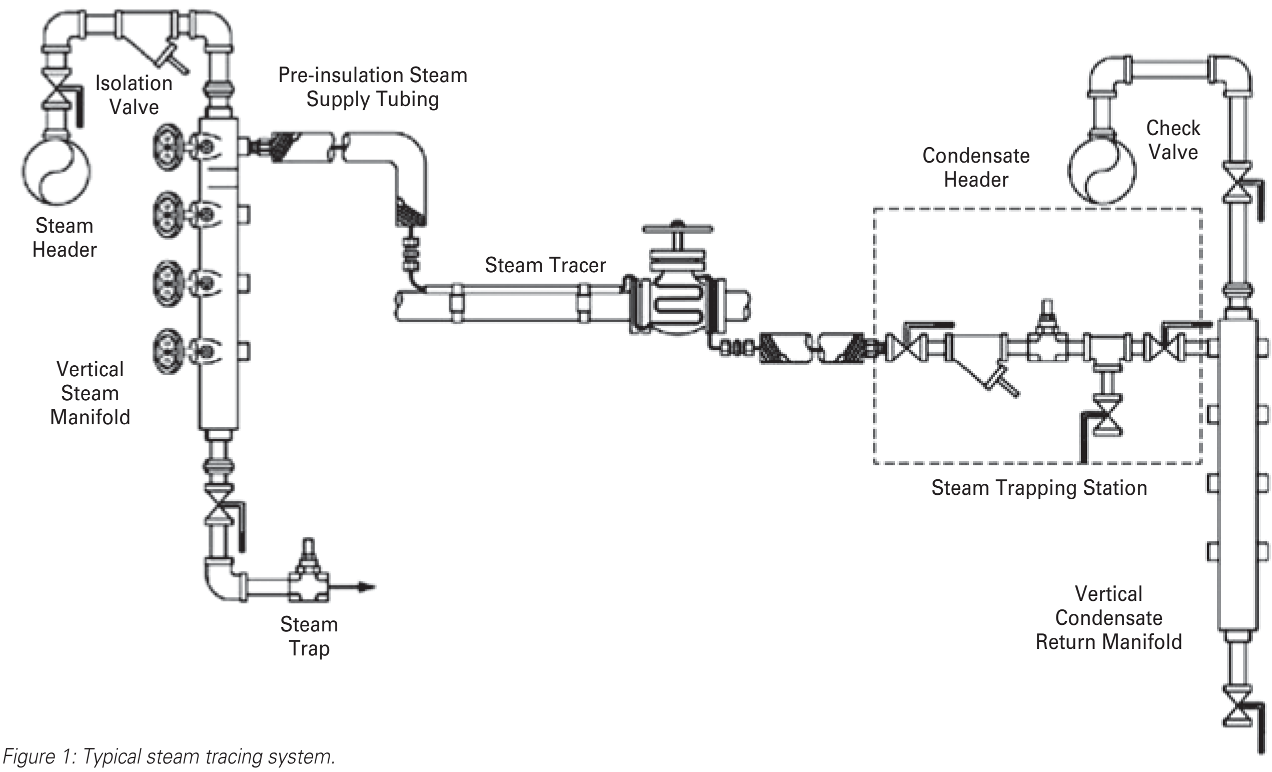


Figure 1: Typical steam tracing system.

Figure 2: 'Safe Trace' installation.

are applied other than steam pressure reducing valves. However, several control methods are available and discussed later in this article.

What is meant by the term 'free steam?'

Steam tracing circuits can frequently use flash steam from hot condensate, steam produced by waste heat boilers, or steam from exothermic processes. Energy from these sources is often referred to as 'free steam.' However, flash vessels, waste heat recovery equipment and various accessories are required to control and transport this steam. The equipment and the accompanying maintenance services are not free.

But, additional fuel is not being consumed to produce this steam, therefore it is a low cost energy source often referred to as 'free steam'. Designing steam tracing systems with today's technology can:

- Significantly reduce energy losses by selecting the best tracer option and insulation
- Lower the generation of hydrocarbon pollutants
- Improve touch safety and reduce OSHA recordable burns
- Lower capital and maintenance costs by optimising circuit lengths and associated equipment
- Minimise thermal expansion in the piping network

The key to both good temperature control and energy conservation is designing and installing tracing systems that control the condensate rate and thereby reduce energy consumption.

Electrical heat tracing has its place

With technology advancement over the recent years, electric heat trace cables can reach even higher temperature ranges. Electrical heat tracing generally requires little or no maintenance and so is an attractive solution to plant maintenance personnel. In addition, far better control methods are available having a positive spin-off on energy usage.

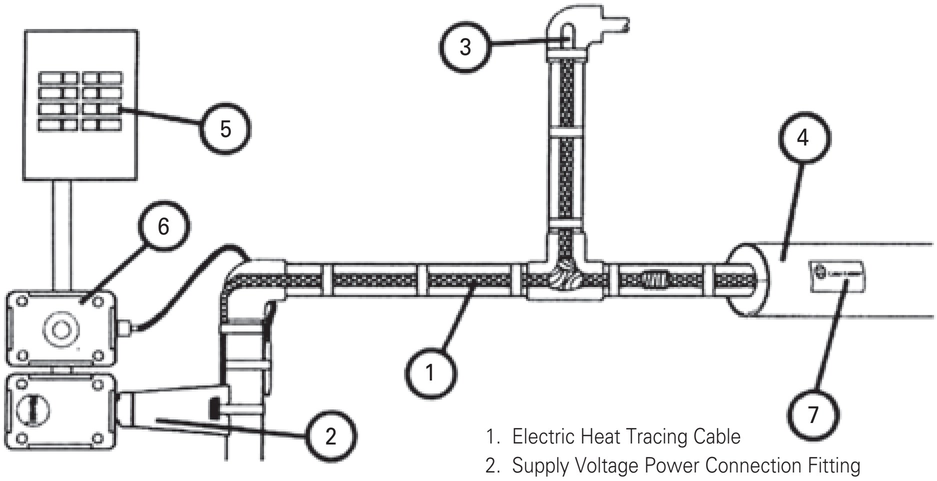
New high temperature polymers and processing methods have led to the development of improved flexible self-regulating and power limiting heating cables. These flexible heaters can be used to hold pipeline temperatures in the 149°C range.

The development of high temperature metal alloys has provided a means to increase the temperature maintenance rating of today's semi flexible mineral insulated electric heating cables up to as much as 500°C with exposure temperatures up to 593°C. See *Figure 3* for a typical electric heat tracing system.

Self-regulating heat trace is typically an energy efficient cable. The resistance of the tracer varies as a function of its temperature. As temperature increases, the resistance of the polymer increases causing a decrease in the power output. The energy output therefore always matches the system's requirements.

Control is *really* where the energy savings become meaningful

The different ways of keeping the pipe from freezing or at its required maintenance temperature are accomplished by different (physical)



1. Electric Heat Tracing Cable
2. Supply Voltage Power Connection Fitting
3. End of Circuit Termination
4. Thermal Insulation and Weather Barrier
5. Branch Circuit Protection Device
6. Control Device
7. Safety Caution Label

Figure 3: Electrical heat trace system.

devices or different control methods. Four different types of control are mainly used in the market today:

- Control by an ambient sensing thermostat
- Pipe /line sensing controlled by a mechanical thermostat
- Pipe /line sensing controlled by an electronic controller
- The CPU based control and monitoring system; with Ambient Proportional Control (APC)

Figure 4: ECM controller for pipe sensing.

The energy saving is found in the control aspect during the varying process flow conditions. The required heat tracing output is normally designed for the 'worst-case' scenario which is at non-flowing condition and adverse ambient conditions.

Conventional ambient sensing thermostats apply full power at a given minimum ambient temperature and switch OFF the power at a higher set point (ambient) temperature, with no regard to the actual energy required on the pipe or heat losses through the insulation. The modern electronic controller, (see *Figure 4*), with a Pt100 temperature sensor directly monitors the temperature changes on the pipe surface (the heat losses). If required, it will automatically switch and provide the required energy to match the heat losses.

Pipe sensing rather than ambient air sensing is particularly suited to reducing the power consumption and applies the power so that it always delivers precisely the amount of heat to prevent the pipe temperature from dropping below the set point. Each process condition might be different but energy savings using a controller with accurate switching in combination with line sensing have consistently been recorded in tests. It can fully optimise the system's heating requirements, resulting in significant energy savings (20% compared to ambient control) [3], considerably reduced operating costs and accumulated power requirements.

Conclusion

Heat tracing systems are not often listed when energy reduction initiatives are being considered. However, when viewed from the perspective of how many metres of heat tracing exist in a typical refinery or chemical complex, the potential for reducing energy consumption and hydrocarbon pollutants can be significant.

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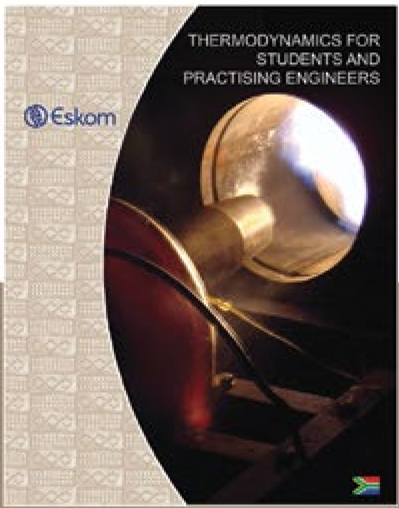

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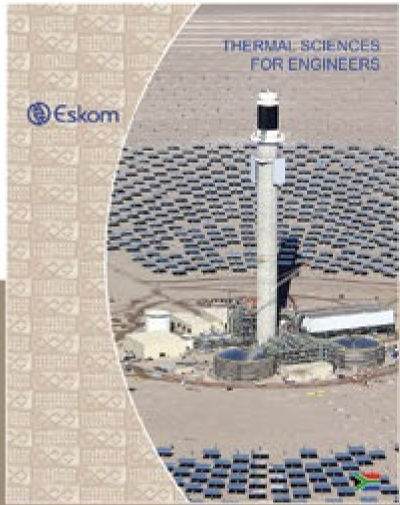

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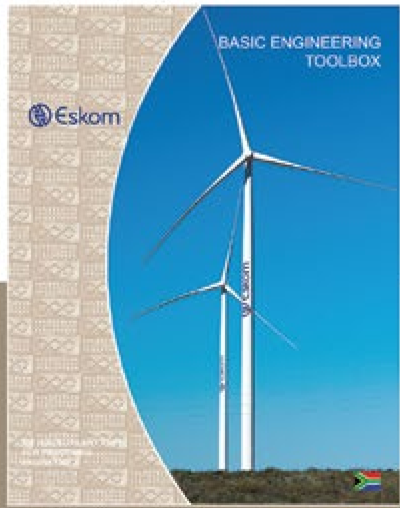

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Chapter 4

Energy savings in other applications

If it is in sub-Saharan Africa, and if it is electrical, lightning poses a risk. New energy technologies, covering large geographic areas, have posed challenges to lightning protection specialists to find better solutions with appropriate levels of protection. These challenges are exacerbated by the increasingly networked and sensitive nature of many of the new energy technologies.

4

Protection of smart power grids and data networks

T Kerchensteiner and M Wiersch, DEHN+SÖHNE

In future, the structures for power generation, transmission and distribution in the high, medium and low-voltage range will be more complex and flexible than they are today.

Higher demands are being placed on technologies owing to political framework conditions and particularly the increasing complexity and wide distribution of the individual systems. New topics, such as smart grid, smart metering or smart home, require innovative solutions. The rapid rise of distributed, renewable energy sources in combination with centralised power stations, energy storage systems and intelligent technologies requires a reliable and coordinated overall lightning and surge protection system.

Germany's transition to sustainable energy involves a variety of measures. In this context, it is particularly important to keep the three objectives of energy policy (environmental compatibility, cost-effectiveness and supply reliability) balanced. Supply gaps quickly cause enormous economic damage and the rapid development in the energy sector inevitably results in higher demands on technologies. This does not only affect power generation and transmission networks, but also distribution network structures where 90% of the transition to sustainable energy takes place [1]. Although the reliability of power supply is constant in Germany, voltage control pushes network operators and municipal utilities to their limits owing to the increasingly distributed infeed from renewable energy systems into low-voltage and medium-voltage networks. To ensure permanent grid stability, voltage control is now implemented by transformer substations instead of large power plants [2].

Sources of damage and protection standards

There are various sources of damage for surges. According to the IEC/EN 62305-2 [3] standard, the causes of surges in case of lightning discharges can be sub-divided into four groups depending on the point of strike (see *Figure 1*):

- Direct lightning strike to the structure
- Lightning strike next to the structure
- Direct lightning strike to the incoming supply line
- Lightning strike next to the incoming supply line

Today it can be considered certain that the radius of destruction around the point of strike is more than two kilometres owing to, for example, highly networked power grids and data networks. In addition, surges are caused by switching operations, earth faults and short-circuits or tripping fuses, Switching Electromagnetic Pulse (SEMP). To minimise damage caused by lightning effects, the following solution

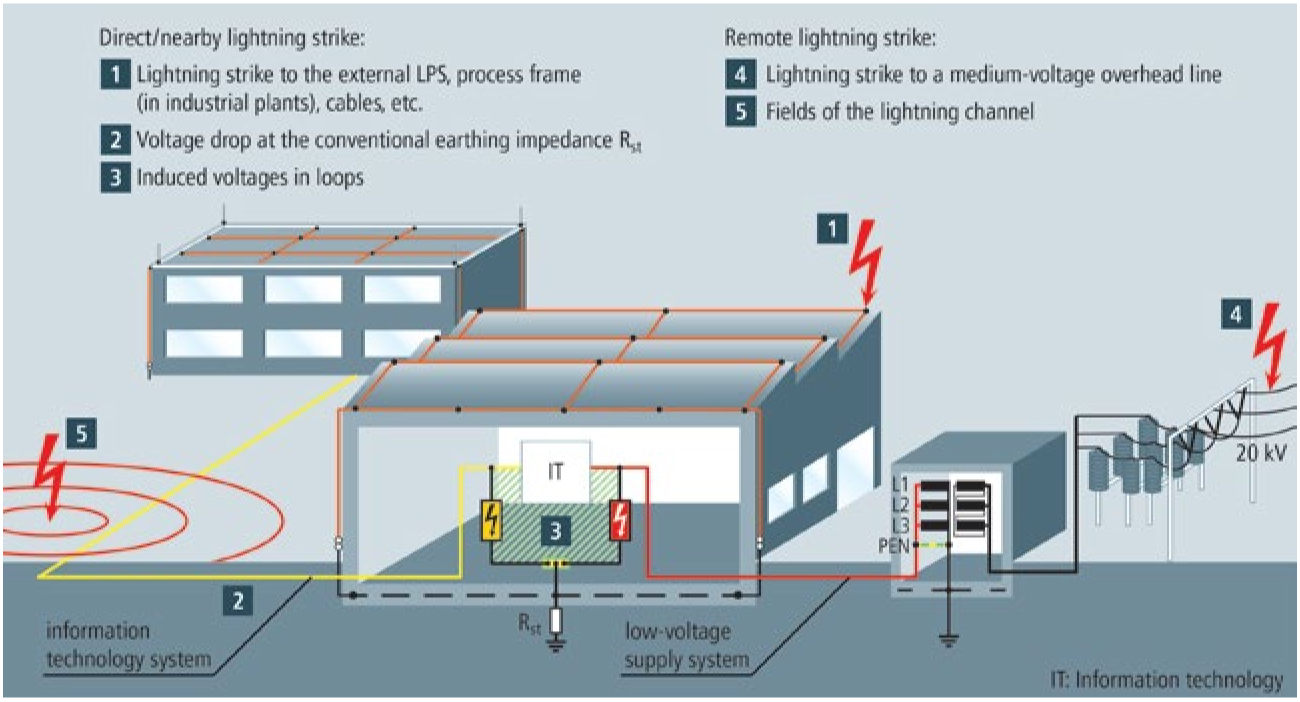


Figure 1: Causes of surges in case of lightning discharges in the power supply system.

approaches can be derived from the relevant protection standards:

- Material damage and life hazard in case of direct lightning strikes to a structure can be minimised by a conventional Lightning Protection System (LPS) according to IEC/EN 62305-3 [3]
- To ensure protection of structures with electrical and electronic systems, particularly if reliable operation and supply are essential, these systems must be additionally protected from conducted and radiated interference resulting from the Lightning Electromagnetic Pulse (LEMP) in case of direct and indirect lightning strikes. This can be achieved by a LEMP protection system according to IEC/EN 62305-4 [3]

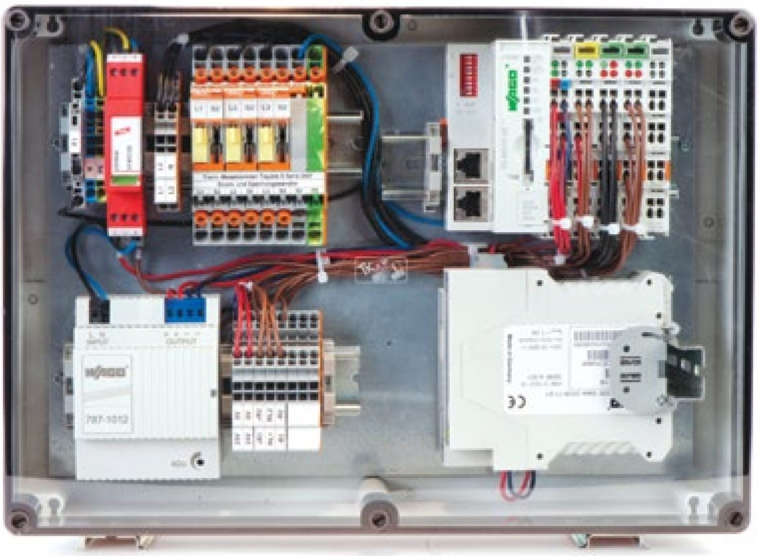
Possible solution approaches and criteria for selecting arresters

A detailed risk assessment of the local threat potential (both for power supply and information technology and communication systems) is required to efficiently protect the technologies used for modern grid expansion such as intelligent transformer substations [4], monitoring and telecontrol systems, adjustable regulated distribution transformers or longitudinal voltage controllers from the sources of damage. This involves certain challenges, for example, lightning and surge protection measures for the electronic components, lacking ease of maintenance and the frequently compact design of the systems.

According to the IEC/EN 62305-2 [3] standard, the total risk of lightning damage consists of the frequency of a lightning strike, the probability of damage and the loss factor. If the technologies mentioned are assessed according to these criteria in conjunction with practical experiences, you will get different individual results depending on the local thunderstorm activity, design and place of installation. To prevent galvanic coupling to the 20 kV medium-voltage overhead line network or outgoing low-voltage lines as a result of a direct lightning strike, a protective device must be installed in the main low-voltage distribution board. This protective device must be selected in such a way that it meets the requirements concerning the lightning current carrying capability, short-circuit strength, follow current extinguishing capability and Temporary OverVoltages (TOV) characteristic. A spark-gap-based Type 1 combined arrester with integrated back-up fuse (CI technology or Circuit Interruption Fuse Integrated) is ideally suited for this purpose. This integrated back-up fuse significantly saves space and installation work compared to a separate arrester back-up fuse and is adapted to the discharge capacity of the spark gap. This ensures maximum performance and incorrect installation is avoided.

If only indirect lightning effects such as inductive or capacitive coupling, conducted partial lightning currents or SEMP are to be expected for the secondary technology according to a risk analysis as per IEC/EN 62305-2 [3], Type 2 (sub-distribution board) and Type 3 (protection of terminal devices) surge arresters are sufficient. Type 2 arresters with the compact CI technology described are available for restricted space conditions.

A surge arrester with integrated Lifetime Indication can be used to implement a preventive maintenance concept. This Lifetime Indication detects pre-damage and indicates this status at an early stage before the surge protective device fails. The arrester can therefore be integrated in condition monitoring systems. This version has a higher discharge capacity than conventional Type 2 arresters, thus increasing the protective effect. In case of wired signal interfaces, injection is to be expected and therefore these interfaces must be protected. A direct lightning strike to the relevant conductor system or a nearby lightning strike close to the relevant conductor system is possible in this case. Therefore, a risk analysis must be performed and the components



DEHN surge protective device for power supply, information technology and communication systems.

must be protected accordingly. The same applies to the transmission systems with external antennas which are only exposed to surges resulting from the field of the lightning channel [5].

A practical solution for the direct installation of protective devices into intelligent transformer substations which considers the possible threat potential is, for example, a complete system for measuring, control and telecontrol systems in a single enclosure (see *Figure 2*). This application includes, for example, network analysis, integration of electronic meters, short-circuit indicators and communication devices. To ensure the required availability, the system in a compact enclosure is protected from surges by adequate arresters.

This is achieved by DEHN surge arresters for power supply systems and arresters which are specifically designed for use in wireless-applications for coaxial device and antenna interfaces (available with SMA, BNC or N-connection for bushing installation). Since only surges are to be expected due to the restrictions described before and the secondary technology is directly integrated in an intelligent transformer substation, Type 2 and Type 3 arresters are sufficient in this case. In this particular application for protecting the secondary technology in an intelligent transformer substation, the neutral point of the transformer is directly earthed in addition to the surge protection measures mentioned. This clearly differentiates the place of installation 'substation' from other places of installation since possible interference impulses on the low-voltage side of the system are discharged via the earthed low-impedance neutral point of the transformer. In addition to theoretical considerations, practical tests of such overall systems can be performed in DEHN's in-house test laboratory [6].

Conclusion

Since the energy and data landscape is becoming increasingly complex and highly networked, the probability of damage to electronic equipment caused by electromagnetic interference significantly increases. This is due to the broad introduction of electronic devices and systems and their decreasing signal levels (and thus increasing sensitivity). Even though destruction of electronic components is often not spectacular, it frequently leads to long operational interruptions. Consequential damage and the costs for clarifying liability issues are sometimes considerably higher than the actual hardware damage [7]. Numerous different lightning and surge protection components are available for preventing such damage in smart grids depending on the relevant requirements. In this context, it is important to consider all potential points of injection, namely both power supply and information technology and communication systems. Space-saving and powerful arresters with CI technology and Lifetime Indication can offer additional benefits. To achieve a consistent and functioning surge protection concept, energy coordination between the arrester types according to IEC/EN 62305-4 must be ensured.

To complement surge protection and to ensure a complete and comprehensive protection system, an external lightning protection system (air-termination system, down conductor and particularly earth-termination system) should be additionally installed and safety equipment should be worn in the intelligent transformer substation. An important topic is, for example, the correct dimensioning of earth-termination systems for transformer stations with respect to the current carrying capability and corrosion, which are described in separate papers [8, 9]. Such an overall protection system meets the increasing demands the industrial society places on a stable and reliable power supply. They require highly available distribution networks with minimum downtime, thus ensuring increased supply reliability and availability.

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Ethernet networks were once things that ran on a shop floor, in the process plant and office. Now, mission critical applications include the monitoring and control of substations, where the same network system provides overall management and control. The planning and design of an Ethernet network must be reviewed.

Planning and designing an Ethernet network for mission critical communications

T Craven, H3iSquared

Ethernet has become the de facto standard for use in mission critical communication networks, especially those used to control power grids. Ethernet standards are constantly evolving, which has led to Ethernet being feasible for use in latency and time sensitive applications, improving the standard on an ongoing basis. Until something completely new and paradigm altering is developed, it is safe to say that Ethernet is here to stay.

However, as is often the case with any new technology, the advancements within Ethernet are outpacing the knowledge and training of those who must utilise it. This leads to networks which, while fulfilling their purpose at the most basic level, fail to fully live up to their potential. A properly designed and implemented network can lead to great savings in both production and time, as problems with network and end devices can be easily identified. With redundancy in place, failures do not have to mean a shutdown of the grid or sections thereof. It is important that the knowledge is in place when designing the network, as Ethernet is no longer a simple technology that can be improvised; it has become a school of its own.

Hardware

One of the main steps when designing a mission critical network is deciding what hardware to use. Budget is obviously always a factor to be considered; however, utilising the incorrect hardware based on a budgetary perspective can lead to greater losses in the long run if the hardware does not live up to expectations. It is important to select hardware that complies with the relevant technical standards for your requirements, and not to pay for functionality that will never be utilised. As stated, Ethernet is a complex group of standards and not all of these will be necessary or even beneficial on your network. For instance, if extremely accurate time synchronisation is required for your network then IEEE1588/PTP [1] (Precision Time Protocol) with a GPS master clock should be considered. If this level of accuracy is not required, purchasing PTP compliant hardware will add unnecessary expense

to the network without any benefit. When considering Ethernet for use in substations or other utility sites, the hardware's resistance to EMI must be considered. EMI can adversely affect transmission of data, especially over copper cables and within the units themselves.

Hardware manufacturer

It is also important to test functionality of a hardware manufacturer before purchasing. Some Ethernet standards are still quite vague in their exact requirements, or are very general in their requirements, so a manufacturer could correctly and legally offer compliance to a standard that turns out not to be the level of compliance required. A current and relevant example of this is the IEC61850 [2] standard for electrical substations. IEC61850 [2] is not a hard and fast standard, but a collection of standards, best practices and suggestions (regarding both the physical and logical aspects) for running a critical network for substation automation. For this reason, some manufacturers will state their hardware is IEC61850 [2] compliant when in fact it barely complies. From a technical and legal standpoint, the statement of compliance is correct and true. This leads to customers purchasing hardware that is not going to meet their requirements, and thus huge losses of capital time and investment.

Avoid vendor lock

Another important point when considering which manufacturer to use is to avoid becoming vendor locked where possible. For instance, if you select a certain manufacturer that offers a proprietary form of redundancy you will then be obligated to use that same vendor for any expansions or replacements in the future (unless that vendor offers backwards compatibility with open standards). Switching to a new vendor at that stage would require a lot of work and a possible complete redesign of the network to cater for a different redundancy mechanism. Using an open redundancy standard instead means that in future you simply need any manufacturer that complies with the original open standard. For instance, a power supplier could spend a few years sequentially upgrading its entire control network across the entire country. If a few years into this upgrade a new technology becomes available that is not supported by the current hardware manufacturer, and the company wishes/needs to use this functionality, all the existing hardware would need to be replaced, even though the majority of it is still new. Using open standards, the option would exist to replace only the hardware on those sections of the grid that require the new functionality, whilst interfacing with the existing hardware where possible.

Hardware selection must be considered throughout the planning phase. Hardware should be selected once the network is planned and the requirements are clearly stated, otherwise the hardware selection could limit your network design possibilities. One must consider not only the present, but also future plans for the network and the expansion thereof. If this is not properly considered in the beginning, expansion at a later date could lead to wasted time, effort and investment. For instance, if there are no spare ports, expansion will require additional switches to up the port count on the existing network. If the network is being expanded to add a single IP camera at each substation, with no ports available one would need to consider buying a new switch per substation, just to add a single connection point. Similarly, if the IP structures have not been properly planned and cannot cater for the upgrade, changing these would take a huge effort and possibly include downtime (i.e. loss of production).

Topologies of the network

The next consideration is the topologies of the network, both the physical and the logical. It is important to note that many of these points would not be done in a linear fashion. For instance, topologies will be affected by the manufacturer chosen and the functionality it has available and will in turn affect things such as routing and redundancy. So all of these points will need to be considered simultaneously to provide the best possible overall solution. The physical topology of the network refers, quite obviously, to the physical layout of the switches and their interconnecting cables. The logical topology, on the other hand, refers to the route that different data will take across the network, and can change depending on the source and destination of said data. While these two are closely tied to one another, it is important to realise that they are in fact different and equally important to consider for a truly efficient, stable and expandable network.

Physical topology

It is generally better to consider the physical topology first in this case, as you will generally be more limited on the physical topology due to geographic considerations (ease of laying cable, distance between sections/sites etc). When planning the physical topology it is important to cater for redundant links. For this you will need to take into account the type of redundancy you are going to run on the network. Some manufacturers will have proprietary redundancies that only cater for ring networks (as stated previously, it is recommended to avoid these proprietary protocols where possible). In this event, installing additional cables beyond those required for the ring is a waste of time and expenditure.

On the flip side of the coin, installing too few cables to provide proper redundancy can lead to issues in the future if one or more of the cables does fail. Cost is also an important factor here, as the cost for provisioning and laying cables can be extremely high depending on the area in which they need to be installed. In some cases wireless links could be considered, depending on various factors (such as available line of sight, interference, distance and more).

A full discussion of wireless communication is beyond the scope of this article; however, in short, wireless can be considered for non-critical information. Although in some unique cases it may be used for critical data transfer, this is not recommended as wireless is not nearly as stable or reliable as wired communications. For applications such as non-critical monitoring, wireless can definitely be a time and money saver.

Logical topology

Once we have a physical topology in place, the next step is to start planning the logical topology. The logical topology will be affected by configurations such as VLANs, redundancy, multicast control and routing (if required). The first step in planning the logical topology is to group various devices around the network together into 'communication groups'. In a nutshell, these are groups of devices that will need to communicate with one another on a regular basis. For instance, CCTV (Closed Circuit Television) devices on the network could all be grouped together into one group, VoIP (Voice over IP) into a second group and so forth. Alternatively one could group devices based on physical location (e.g. all devices in substation A will be in one group, devices in substation B in another group etc). Depending on the network, one may want to group devices based on a combination of these two components. For instance each substation could be its own group, with subgroups for devices with different functionality.

While there is no set rule for grouping devices together, the most important point to keep in mind is that devices that will be communicating with each other constantly should be kept to the same group as much as possible. It is possible to route information between the logical groups (or VLANs); however, this puts increased strain on routing hardware, and can lead to delays in data transmission as we get a 'traffic jam' (or bottleneck) at the routers interface to the network. One also wants to avoid routing any critical, latency sensitive data between VLANs, as once again this can add delays. At the same time, however, not separating devices at all means that the network will become very 'noisy' with background traffic, such as broadcasts. While this traffic is essential to correct network operation, too much background traffic means that critical traffic and relevant data may be delayed. For this reason, it is important to find a balance when grouping devices on the network. VLANs and proper traffic segregation are a big component of the IEC61850 standards, and should not be taken lightly. A well designed VLAN structure across the network will have a significant impact on providing a stable and reliable network and, next to topologies, is probably one of the most important components to design correctly.

Once there is an idea of the devices that will be on the network and how they need to be grouped, IP address ranges for each VLAN can be considered. When dealing with IP ranges for a LAN, the selection must come from the private IP address range:

- 10.0.0.0 to 10.255.255.255
- 172.16.0.0 to 172.31.255.255
- 192.168.0.0 to 192.168.255.255

These ranges of IP addresses are special in that they will NOT be routed across the internet. This means that these private ranges are free to use as they will never be exposed directly to the internet and thus we will not run into an issue with duplicate IP addresses on the internet. The different ranges are suitable for different networks depending on (a) the number of hosts (end devices) required on the network and (b) the number of sub-networks (different devices 'groups') allowed on the network. Selecting the correct range in the initial design phase is highly important, as changing an IP range at a later stage will generally either involve some downtime or alternatively can be extremely complicated (if downtime must be avoided) and will require a specialised solution and additional hardware for the change. One wants to select a range that caters for the number of devices in the initial network as well as any future expansion. At the same time, one needs to make sure that different subnets will be separated correctly and that the IP ranges comply with any requirements for the network. For instance, the new network design may be part of a larger network and thus you may be assigned an IP range to use. In this case care must be taken not to interfere with other ranges on the network, while still using your (limited) range to cover all current and future device requirements. This will be done by subnetting (dividing) the given range into smaller subnetworks. Generally these will correspond to the VLANs used, as in order to route between different VLANs they need to be assigned different IP subnet ranges. Properly splitting and allocating a subnet to cater for an entire network or network segment is an involved process and should not be undertaken by anyone without a working understanding of IP ranges, routing and VLANs.

As an example

A hypothetical new utility company for South Africa is in the process of setting up control centres and substations and has decided to use Ethernet as the communications technology to link all these different sites. The plan is to use a large IP subnet range for the entire

4

country-wide WAN (Wide Area Network) and then split this larger range into 10 subnetworks, one of which will be used for countrywide admin, with the nine remaining to be split amongst the nine provinces. A different group of engineers is in charge of each of the provincial networks. As long as each engineer does not use IP addresses from outside of his/her allocated range there will not be an overlap, so the different groups do not have to consult constantly with one another regarding the IP design. (Note that this does not take into account the company standard etc for the network design, but does give a basic example of how IP subnetting works). A single provincial network's IP range may then be split into smaller subnets for different processes (VoIP, control, CCTV, monitoring etc.). This would generally be an acceptable level of subnetting to provide a stable and clean network. Splitting up these subnetworks much further may start to cause problems as more and more data has to be routed between the different subnets.

Also it is important to note that each time a network is subnetted we lose two usable addresses (due to the way Ethernet works these addresses become special addresses for the subnet that cannot be assigned to actual end devices), another reason not to overly subnet the network, as eventually one may run out of addresses to be used for end devices.

Once these major points have been covered, we should have a good foundation for planning other components and functionality on the network. We have an idea of the physical and logical topologies for the network, as well as the addressing (IP ranges) and VLANs that must be implemented.

This means that we can start to plan some of the other parts of the network, such as the specific redundancy and various traffic control aspects. In some cases these may simply be an added functionality or a way of easily monitoring the network, in other cases they may be critical to the correct running of the network. Which parts should be considered critical and which are simply 'added extras' will depend on the network itself and the requirements thereof.

Redundancy

One of the most critical functionalities to be considered on any mission critical network is redundancy, which we have mentioned in passing in the course of this article multiple times. However, redundancy is important enough that we will go over it in more detail here. Redundancy means that the network caters for certain failures, such as cables breaks or hardware failure. In the event of a failure, the redundancy mechanisms in place will attempt to 'recover' the network to a point that communications are not interrupted, thus allowing the failure to be addressed without the need for the entire network to be brought to a standstill. These recoveries need to happen extremely quickly, especially in the context of communication networks for SMART grids. A loss of communication between sites, even for a second or two, can lead to devices automatically shutting off the flow of electricity on portions of the grid as a matter of safety.

Cable redundancy

There are many different types of redundancy; however, generally when people speak about redundancy relating to a communications network (without explicitly stating the type of redundancy) they are referring to cable redundancy. Before we look at the different cable

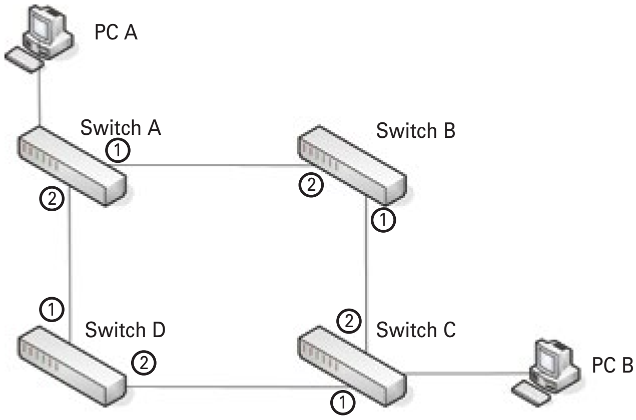


Figure 1: Basic ring topology without redundancy activated.

redundancy mechanisms available, let us look at why they are needed on an Ethernet network.

Consider the basic network (see *Figure 1*) - assume this hypothetical network is not running any form of cable redundancy yet. If PC A needs to establish communications with PC B, A will start by sending a type of message called an ARP request (Address Resolution Protocol). This is an example of a broadcast packet, meaning that rather than a specific device/s as its final destination, this message will be broadcast or sent to every device on the logical network. Note there are other ways of generating broadcasts, as well as multicasts (which are similar to broadcast in regards to the requirement for redundancy). For this example we will just look at the most common broadcast, an ARP request, as we are more concerned that it is a broadcast rather than the actual details of the message being broadcast.

PC A will send this broadcast to Switch A, which then propagates the message out of every port it has active except for the port on which it received the broadcast. So, Switch A sends to both Switch B and Switch D. The message received by Switch B is sent on to Switch C (again, it sends out of every port except that on which it received the broadcast). Switch C sends that message to PC B and to Switch D. PC B then responds (directly to PC A, so this message is not a broadcast) with its machine address, and unicast (one-to-one) communications can happen between the two PCs. Let us not forget that in the meantime, Switch C would have sent the broadcast on to Switch D, which then passes it back to Switch A, and the whole cycle begins again. We can see quite clearly, with this physical loop on the network, that our broadcasts will effectively continue circling the network indefinitely. As more and more broadcasts are introduced to the network, this erroneous traffic keeps building up, to a point where the communications links and devices are so busy transmitting this 'waste' information that normal and critical data is not able to 'fit' on the network. In fact these broadcast storms, as they are known, can be so severe as to hang up end devices such as PLCs and older PCs or servers as all of their processing power is taken up having to inspect the packets generated by the broadcast storm.

The basic point described is that: *Ethernet does not like loops!* The simplest solution is to remove one of the cables, thus breaking the loop and interrupting the broadcast storm. In this case each device on the network only receives the broadcast packet once and then it is done, rather than storming around the network indefinitely.

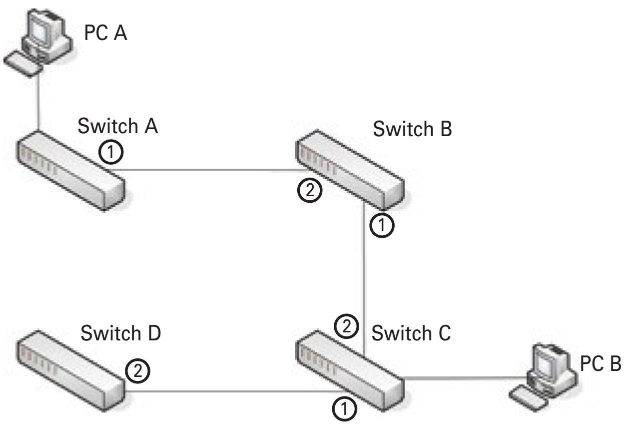


Figure 2: Basic star topology – No redundant links available.

In *Figure 2* it can be seen that we have solved the issue of the broadcast storm and have changed the network backbone (connection between switches) from a ring to a line/star topology. However, what happens if we now lose the cable connecting switches B and C? Communications between PC A and PC B will no longer be possible at all, as there would be no communications path remaining between their network segments. This leads us to the reason redundancy was created and is used, especially on mission critical networks. While cable redundancy mechanisms work in different ways, their outcome is the same: they allow us to have physical loops on the network, yet they logically disable connections so as to break any communications loops on the network (such as in the image below, a redundancy mechanism has effectively 'broken' the link between A and D, even though the physical cable is still connected). In the event that another cable break leads to communication interruption, the mechanism will attempt to re-enable any redundant links held as back-up so that communications are not interrupted.

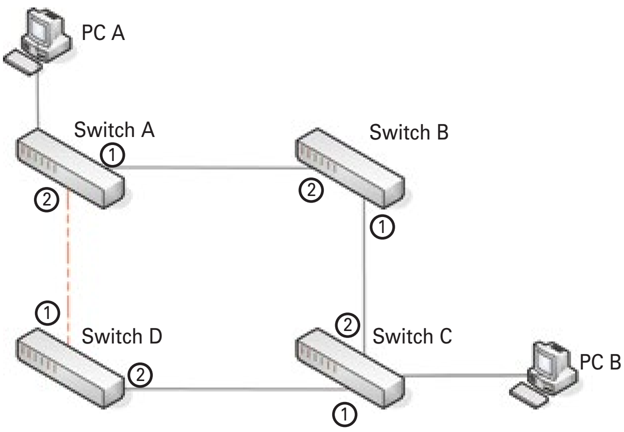


Figure 3: Basic ring topology with redundancy in place.

There are many redundancy protocols available, a number of which are proprietary to certain manufacturers. RSTP (Rapid Spanning Tree Protocol) is one of the most commonly used open standards and is supported by most hardware manufacturers. However, RSTP can take up to 30 seconds to recover in a worst case example, and so can be unsuitable for certain applications. In these cases one may need to look at either a proprietary redundancy protocol, or alternatively one of the newer open standard redundancy protocols to be released. Either HSR, PRP or HSR (High-Availability Seamless Redundancy) and PRP (Parallel Redundancy Protocol) work by transmitting data along two different paths to its destination. This means that in the event of a failure on Path A, the data will arrive via Path B, without any further delay or requirements for retransmission of the data. In other words, bumpless redundancy does not require time to recover from a failure. These two redundancy protocols provide zero recovery time, which is great for mission critical, latency sensitive applications, however, the capital cost will be more than required for standard redundancy hardware.

When it comes to cable redundancy, it is best to look at it from the perspective: How much redundancy can you afford not to have? Will a cable break lead to complete shutting down of the entire grid (or a section thereof) or is it simply going to mean a few people lose out on some non-critical monitoring data. Installing an extra cable and redundancy to prevent a countrywide blackout is definitely worthwhile; however, installing the same cable to ensure a single user has 24/7 access to personal emails is not.

These are obviously extreme examples, but this is the decision process for any redundancy. Weighing the cost (whether money, time or effort) verses the potential losses if the redundancy is not in place will determine if it is worth it. There is potentially no upper limit to redundancy (although using every port on a switch to create a redundant connection to another switch is obviously not useful at all). Budgetary considerations will help determine the specific limit for your network.

Whilst the best option could be to run redundant hardware at every point in the network, with redundant power supplies and multiple redundant uplinks between sections of the network, this can quickly deplete even the largest of budgets. Having little to no redundancy could mean incurring huge losses by the simple accident of a cable breaking. Once again, finding the balance is the biggest trick here, and should not be undertaken by anyone without a working knowledge of Ethernet and the redundancy options available.

Hardware redundancy

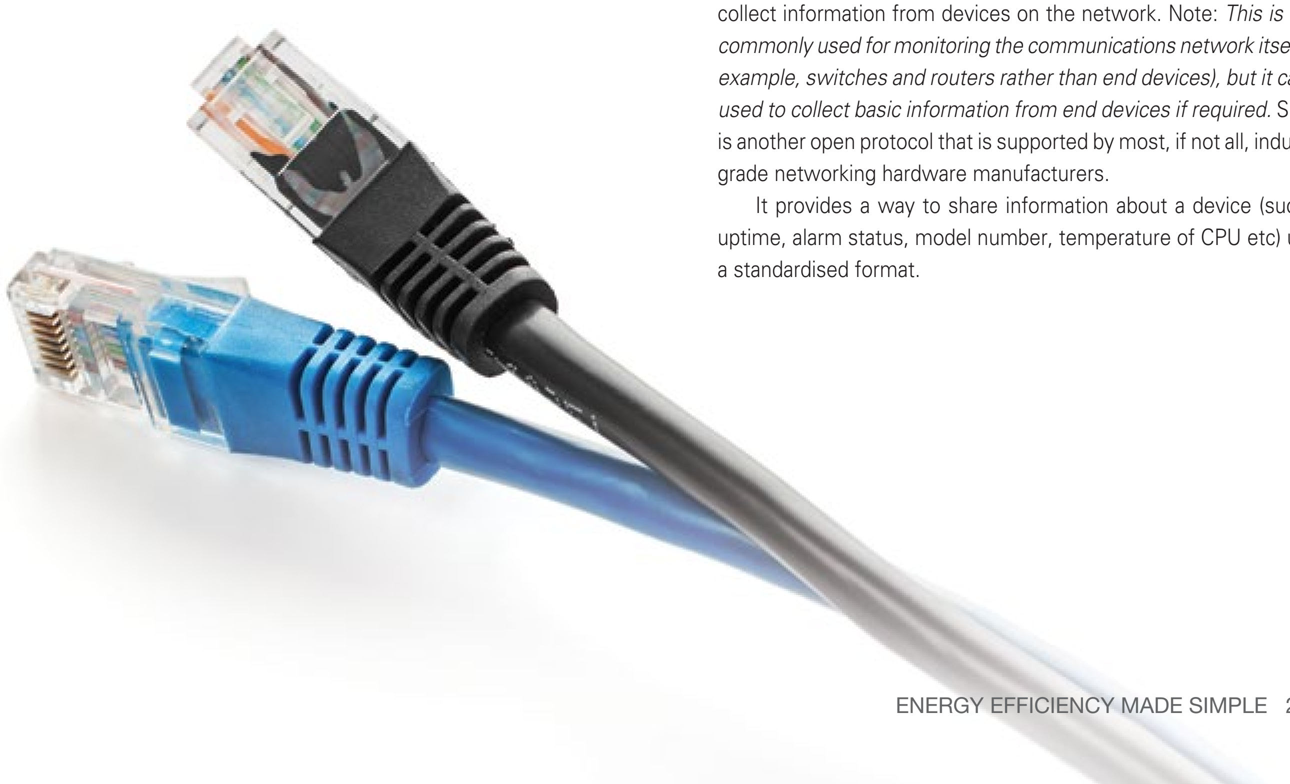
Cable redundancy is a topic that warrants special attention when planning and designing a network. In fact redundancy is one of the core decisions of the network as it can affect many other decisions. Cable redundancy is not the only redundancy available, even though it is the most commonly discussed. Another big redundancy point that should be considered is hardware redundancy options. Whilst cable redundancy protects against a communications link or cable breaking, hardware redundancy is more concerned with what happens if a piece of hardware or a component fails.

Power supply redundancy

One of the simplest of these, yet an overlooked or misused option, is power supply redundancy. Units with dual redundant power supplies, when installed properly, will prevent equipment from shutting down in the event of one power supply failing (and provide a level of load sharing between the two supplies, thus extending their lifetimes). It is important that this is implemented correctly. For instance, daisy chaining power from a single supply to power both redundant inputs defeats the purpose. Although this will prevent shutdown if only a single power input on the device fails (although in some cases even this may break the daisy chain and prevent power from reaching the second power supply), there is no protection if the actual supply fails. Rather, both power inputs should be connected to two completely separate supplies, so that in the event of one supply failure the second will take over powering the device.

In terms of communications equipment we can also look at router redundancy. If a router joining two important network segments fails, communication between those segments could be lost. In some networks this could mean losing communication to a single or multiple substations, or alternatively disconnecting a branch from the main control centre. In some cases this may not be a critical problem, and time could be taken to solve the issue. In other applications this loss of communications could lead to the loss of time, income and production. Generally one should try prevent routing mission critical data (due to the additional delays imposed by routing), and in some cases (notably GOOSE (Generic Object Oriented Substation Events)) certain data cannot be routed at all. Once again, this comes down to a weigh-up between how much an additional router would cost versus the potential losses if the routing fails. Routers provide non-critical services such as remote access control. In these cases a lost router may mean a technician has to travel to site rather than sorting a problem out remotely; this could be deemed an inconvenience rather than a critical issue.

In cases where failure of a router could mean critical communications losses, the option to use VRRP (Virtual Router Redundancy Protocol) can be considered. This protocol works by effectively creating a single virtual router from two or more physical routers. End devices' routing needs will be serviced by the virtual router, without them being aware of which router was physically handling the routing. In the event of failure of the primary router, the secondary will take over with minimum downtime (a few seconds for most basic networks), and in a manner that is transparent to the end devices. Without this protocol, failover between two routers would either need to be done manually (by changing the configuration of the end devices) or would require multiple gateway configurations in end devices (and end devices, especially PLCs, IEDs and RTUs, will not allow for multiple gateway configurations).



Switch redundancy

Actual switch redundancy is a lot harder to cater for, as a switch provides an end device point to which it connects to the network. If a switch fails completely, any interfaces connected to that switch will obviously lose connection to the larger network. Whilst we can look at options such as redundant power supplies, the only way to allow for an actual switch failure is if the end devices support multiple Ethernet connections. For instance, a PC that has two network interfaces and the correct software could be physically connected to the network via two separate switches. In the event one switch fails, the second connection could be used to transmit data to the network. Obviously in this case the two connections would be required to be on different physical switches or at least on different modules in the switch.

Monitoring redundancy

Many different redundancy options are available for communications networks and they all have in common: Redundancy is next to useless if not monitored! If we have cable redundancy on the network, and our redundant cables all break but no-one is actually monitoring the situation, we are left in a position where the network is no longer redundant, and none of the broken cables is being addressed. This means that if another cable breaks we will experience communication interruptions on the network. Not monitoring redundancy is simply delaying the inevitable, we may cater for the first cable break (or first few breaks) but beyond that the network is no longer redundant. If the situation is being correctly monitored, the redundancy in place will recover from the failure and communication will not be lost while the issue is being dealt with.

Monitoring of a network can be done in a variety of ways, however, the easiest, most automated and most reliable is to install and commission an NMS (Network Management System). An NMS uses a protocol called SNMP (Simple Network Management Protocol) to collect information from devices on the network. Note: *This is most commonly used for monitoring the communications network itself (for example, switches and routers rather than end devices), but it can be used to collect basic information from end devices if required.* SNMP is another open protocol that is supported by most, if not all, industrial grade networking hardware manufacturers.

It provides a way to share information about a device (such as uptime, alarm status, model number, temperature of CPU etc) using a standardised format.

Files called MIBs (Management Information Bases) can be provided by manufacturers, and are effectively a dictionary for SNMP to understand manufacturer specific information about a device. Once again cost must be considered, as an NMS and its attached license will generally not come cheap. In almost any mission critical network, the benefits gained from having an NMS on site far outweigh the initial CAPEX (capital expenditure) and OPEX (operational expenditure) involved, especially when troubleshooting issues on the network. An NMS will give information in a couple of minutes that could take hours or even days to trace down and collect manually. Just by this an NMS will pay for itself after a couple of small issues, simply due to not calling a third party to troubleshoot the network.

An NMS uses SNMP to gather information from devices periodically (called polling), and also for devices to send information to the NMS in the case of a critical change such as a port failure on a switch (this process is known as trapping). Along with this, the NMS will also use protocols such as ICMP (Internet Control Message Protocol, i.e. ping) to test uptime of devices, and will test services such as HTTP (for web access to a device), FTP (for file transfers) etc. The NMS will then provide all this information in a summarised format and will provide a visual map of the network. Various alarms can be marked on the visual map to provide a quick and easy way to view the overall status of the network. An NMS allows network administrators to be proactive rather than reactive by pointing out potential issues before they become serious problems. An NMS can be closely compared to a SCADA system in that it provides a visual representation of the network, and monitors and possibly controls functionality.

Remote access

Remote access is another hot topic when dealing with a communications network and, as long as it is properly implemented and secure, remote access can lead to huge savings of time and effort when troubleshooting or maintaining a network and its attached devices. Remote access refers to a user gaining access to the network and its attached devices from a location not directly attached to the network. This will normally use the internet as the intermediate network via which the user gains access to the site, but can also use a private WAN (Wide Area Network) such as a privately owned cellular network covering the locations in question.

Using one of many VPN (Virtual Private Network) protocols available, the user will then create a secure tunnel through the intermediate network to the site. This tunnel will be encrypted and authorise any users/data attempting to traverse it, so data travelling along this tunnel will not be readable by potentially 3-4 times as long as when compared to the actual troubleshooting process. When an issue is discovered, this means that malicious users are in the intermediate network (which is obviously a concern when using the internet as the intermediate network). Users are therefore able to troubleshoot, configure or collect data off devices from the comfort of their home or office, rather than having to travel out to site or to a central control room to do so. This can prove invaluable, especially in cases where travelling to and from site can take a long time. In some cases in the time travel takes, technicians and engineers can address the issue. This adds up to reduced travel time, quicker troubleshooting response and increased productivity in the long run. It is critical to make sure that the security offered by the VPN router is high enough that the remote access can be properly secured. A few years ago security for VPNs was not as advanced as it is today, so remote access was generally never used on mission critical networks. With improvements in the authorisation and encryption protocols in use, a VPN can be set up that provides stable, reliable, remote access with the peace of mind that comes from properly implemented security. Finally, when implementing security it is critical that internal company policies are created to support the security system. For instance, securing your remote access with a VPN is a waste of time if the username/password and relevant certificates are spread around the company (and possibly outside of the company) in an uncontrolled fashion.

Case in point

In a recent case, an unspecified mission critical network in South Africa was providing VPN access to various third party companies for monitoring and control purposes. After a few months, the list of allowed VPN users was in the double digits, and suddenly it was discovered that unknown users were using the VPN to gain access to the network and interfering with PCs on the network that they had no business logging into. At this stage most of the VPN connections were cancelled and new policies were put in place to better control the VPN access.

Fortunately, no malicious damage was caused by the unwanted remote access, but this could have turned into a serious problem. The cause of the issue was determined to be the fact that many of the third party companies started sharing the VPN login details amongst various members of the company, and eventually this became uncontrollable. Whether the unknown users had malicious intents or not was (fortunately) not discovered before the VPN access could be better controlled.

Conclusion

In this article we have discussed some of the most salient points that must be covered when designing and planning an Ethernet network. Some sites may require other protocols and features that have not been discussed, while others may not require all the points in this article. Every application is unique and should be planned for with this in mind. Some set-ups that work perfectly for Application A may not work for Application B. IP ranges and VLANs will depend on the number of devices, their purpose and their physical locations, as well as the overall topology of the network and the requirements. For this reason it is important to spend time on the planning phase and invite specialists to provide information and insight where required, in order to arrive at the best possible network design that caters not only for the network at hand, but also for any future upgrades or changes to that network. Skimping on the planning and design phases will generally lead to a network that does not perform to the best of its abilities, and the time saved by doing so will be far outweighed by the additional time wasted on troubleshooting and design changes during commissioning and live running phases.

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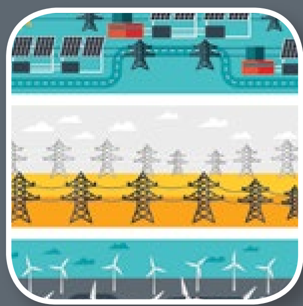
[2] IEC61850. 2011. Communication Networks and Systems in Substations.







Chapter 5

Maintenance and system issues

Without cables, electrical energy is not going anywhere. New energy opportunities provide some unique challenges, with cables having to be used in typically harsh African environments. New standards and technologies have evolved to adequately serve the rapidly expanding alternative energy market. But the cable remains the key factor.

Making the renewable energy connection

H Scholtz, Aberdare Cables

South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) is the fastest growing initiative of its kind in the world, with private sector investment in electricity generation set to flourish.

The main sources of renewable energy in the South African context include solar PV, Concentrating Solar Power (CSP) and onshore wind power. Adequate cables, specifically tailored for each solution, are required to effectively transfer electrical energy - however, SA has unique environmental conditions that need to be factored in and, of course, with each new technology comes new demands. These are some aspects that need to be taken into consideration when designing renewable energy cables for this ever-changing and ever-growing sector.

Cable perfection

There are a number of challenges to overcome and aspects that need to be taken into account when designing cables for South African renewable energy projects:

- **Dc operation** – Cables in standard systems operate at ac. However, photovoltaic cells are dc devices and many of the cables used for solar plants must, therefore, operate at dc
- **Aluminium conductors** – Most independent power producers utilise/require aluminium cables but generally these cables are connected to copper components. This means that bimetallic corrosion must be prevented through the use of bimetallic connectors
- **Ozone resistant (O_3)** – If projects are situated in highly polluted areas or cities (such as rooftop solar PV) cables could be exposed to higher levels of O_3 from the air. It is important that the cable's outer jacket material is protected from this aggressive form of oxygen, which could cause deterioration in certain instances
- **Oil resistant** – This becomes an issue in plants that utilise solar systems that track the sun or in wind turbines - grease or oil leaks could compromise cable integrity
- **High degree of flexibility and torque resistance** – This is a particular necessity in solar and wind plants that comprise moving components. Cables need to be agile and flexible in order to withstand rotational movement in combination with tensile forces
- **UV resistant** – UV radiation in South Africa is well known to be amongst the highest in the world and care must be exercised in using cables that may not necessarily have been tested for exposure to UV weathering
- **Tougher outer sheaths and increased abrasion resistance** – Some solar and wind plants are located in tough environments; soil is of poor quality and could contain stones and rocks that could damage cables. Cost pressures on these projects often result in un-armoured Low Voltage (LV) and Medium Voltage (MV) cables being specified for direct burial application. These cables are not protected by an additional armour and bedding layer and will require special care. It is recommended that MV cables are designed with Medium-density Polyethylene (MDPE) sheaths to ensure that the outer layer of the cable is more resistant to abrasive materials. Anti-electrolysis designs with a conductive outer sheath layer and enhanced radial thickness, as applicable, should be considered for added protection
- **Water resistant** - Longitudinal water blocking designs, complying with SANS 1339 [1] test requirements, have also been used in areas where cable sheath damage could lead to water ingress
- **Single core cables** – High power requirements in wind farms lead designers to use single core cables for the transmission of power from the wind tower to the substations. Although the behaviour of single core cables in terms of induced metallic screen and armour voltages (or induced currents) is well understood, problems do occur in practice. Core arrangements, cross bonding and the selection of sheath voltage limiting devices play an important part in ensuring a reliable system

Quality, quality, quality

With a number of Independent Power Producers (IPPs) - who make use of EPC contractors with overseas experience - entering the renewable energy sector (mostly from foreign markets), manufacturers have had to produce cables that are compliant with compulsory South African standards and meet the international requirements of power plant designers. It is advisable that designers consult with cable manufacturers during the initial electrical design phase of renewable power plants as the correct application advice and specifications will ensure that performance requirements are met for a particular project and that local regulations are adhered to. Potential mistakes of this kind are costly to resolve at later stages of project execution.

The cables which are supplied for South African renewable projects are required to meet local standards, namely SANS 1507 [2] for low voltage and SANS 97 [3] or SANS 1339 [1] for medium voltage cables. These standards are compiled generally to comply with the applicable IEC standards (for example, IEC 60502-1 [4], IEC 60055 [4] and IEC 60502-2 [5]), but include additional requirements that cater for local conditions and regulations.

A major component of the electrical cable requirements for CSP and solar PV plants is covered in the standard SANS specifications (with some additional requirements) but the need for small sizes (typically 6 mm^2) of flexible conductors with thermosetting insulation and sheathed, although covered by SANS 1507 [2], is not a standard design used in South Africa. This need has, however, emerged in the last couple of years through the renewable power projects launched by government.

Solar PV cables produced in South Africa have, therefore, been designed and manufactured to the SANS 1507 [2] standard by leading players in the sector in either a reduced halogen emission xlpe/pvc (LH) or halogen free xlpe/eva single core flame retardant, UV stable designs. Local legislation does not require the use of halogen free cable designs for fixed installations, but current standards do ensure that cables are prevented from releasing harmful halogens, toxins or significant volumes of smoke if they do burn during a fire.

Solar cables make use of flexible Class 5 tinned conductors for flexibility and require compatibility testing in order to ensure that insulation and sheathing compounds do not mutually affect one another during operation. UV resistance testing is carried out in accordance with the American standard, UL 1581 [6], which utilises the American Society of Testing and Materials method (ASTM G155-00 [7]).

The IEC TC20 Working Group (WG) 17 is currently in the process of drafting a new standard for solar PV cables (IEC 62930 [8]) with participation from the Association of Electric Cable Manufacturers of South Africa (AECMSA). The chairman of the AECMSA Technical Sub-Committee will lead the committee on a proposal to the SABS for the introduction of a new part to SANS 1507 [2], which will cover solar PV design and performance requirements specifically.

Future outlook

Solar PV cables are required for rooftop PV systems and it is envisaged that the current power situation in South Africa will lead to some homeowners and businesses wanting to be self-sufficient during power outages or able to make energy cost savings during the day when the sun is up. This will lead to an increase in the demand for PV cables from a residential and corporate perspective.

Further to this, with the onset of future smart homes, smart businesses and smart energy projects, cables could take on multiple roles, providing solar and grid energy as well as broadband access. Cables in renewable energy plants could then communicate the status of energy generation more effectively and ensure the efficient, remote control of grids and systems.

More and more renewable power generating plants are being constructed or planned on the African continent and it is envisaged that South African consulting engineers, with the experience gained in local renewable projects, will specify cables compliant with the SANS standards for use in these projects. This will lead to cross-border opportunities for local cable manufacturers.

Even though aluminium, which is being used more and more in renewable energy cables, is less attractive to thieves (from a value perceptive), cable theft is likely to remain an issue going forward.

The marking of cables with unique identifiers, so rightful owners can be identified, and other mitigation methods should not be discounted.

Conclusion

A recent report by the Council for Scientific and Industrial Research (CSIR) states that solar and wind projects in South Africa generated an R8,3 billion benefit for the country from January to June this year. Opportunities are rife for local cable manufacturers who are able to meet the demand for quality, durability and sustainability. South Africa's local environmental conditions drive the need for innovation in cable design, ensuring protection against water, UV and ozone exposure as well as flexibility.

Stricter standards will soon come to the fore, with low halogen or halogen free cables becoming more prevalent. Cables will not only have a significant role to play in transmitting much needed renewable energy to where it is required most, but will also feature in the smart homes and smart grids of the future.

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[4] IEC 60502-1. 2004. Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV). Part 1: Cables for rated voltages of 1 kV ((Um = 1,2 kV) and 3 kV (Um = 3,6 kV).

[5] IEC 60055. 2005. Paper-insulated metal-sheathed cables for rated voltages up to 18/30 kV (with copper or aluminium conductors and excluding gas-pressure and oil-filled cables).

[6] IEC 60502-2. 2005. Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV). Part 2: Cables for rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV).

[7] ASTM G155-00 (superseded by ASTM G155-13). Standard practice for operating Xenon Arc Light apparatus for exposure of non-metallic materials.

[8] IEC 62930. Electric cables for Photovoltaic systems.

Any cable carrying a current dissipates energy as heat. Heating a cable to temperatures outside of prescribed limits can result in permanent damage and put your entire distribution system at risk. Techniques exist that allow you to manage the life of your cables by properly predicting both steady state and transient cable temperatures. This requires a sound understanding of the cable rating.

Preventing damage to underground cables

JJ Walker and TR Becker, Walmet Technologies

The current ratings of cable installations are normally determined following the guidelines given in the international standards for steady state rating and emergency ratings. An in depth knowledge of the standards is required, which has resulted in only specialists being able to do the calculations. It has been proved that the ratings can also be determined using Finite Element Simulation (FES) software but this again requires the programs to be available as well as the knowledge to apply these programs.

This article introduces a model where the service to develop the cable models in the software is done by a third party and the client then performs the simulations by means of remote access to the service provider server.

The calculation of cable ratings can be divided into two distinct sections.

The first is the calculation of the sustained or continuous steady state rating and the second, the calculation of cyclic or transient ratings. The calculations for the continuous rating of a cable are performed by developing a model of the cable on the principle that heat flow is analogue to the electrical current flow in an electrical circuit [1]. This is based on the methods given in IEC 60287. The calculation of the transient rating of a cable system is normally based on the lumped capacitance method which involves drawing up a ladder network of a cable and then reducing it to a two loop circuit for analytical calculation purposes [2]. Both the steady state and transient methods rely on mathematical calculations that require a sound knowledge of the theories involved.

A number of different computer models have been developed in the past to allow the operator to input certain variables; software will then do the calculations. A Dynamic Feeder Rating (DFR) System [3] requires a continuous input of cable system data (temperatures, currents, etc) to be available before the required calculations of the emergency rating can be performed. Another system [4] uses the mathematical functions and relies on the availability of information on the cable system prior to the application of the step load.

Although these systems and methods will give the required results, they have some disadvantages, namely:

- The computer programs are not freely available
- They require an advanced data acquisition and library system

IEC60287-1-1. 2006. *Electrical cables – calculation of the current rating – current rating equations and calculation of losses.*
IEC 60287-2-1, 2006. *Electrical cables – calculation of the current rating – thermal resistance.*

- They require high level knowledge to build the cable models into the database
- It has been shown [5] that cables can be modelled in FES programs and that the results for steady state and transient ratings compare favourably with the results obtained from traditional mathematical methods

When carrying out computer simulations based on the FE method, the cable is drawn and specified in the program in its finest detail for analysis. The only difference between specifying the cable in detail and using a general model as far as the software program is concerned is the time that it takes to do the analysis. It is also obvious that the degree of accuracy of the results done with FE analysis is a function of the detail specified in the model used. With the availability of powerful computers the analysis time for the most detailed (and accurate) simulations is reduced to minutes. A typical cable model that was used for steady state as well as transient simulations is shown in *Figure 1*.

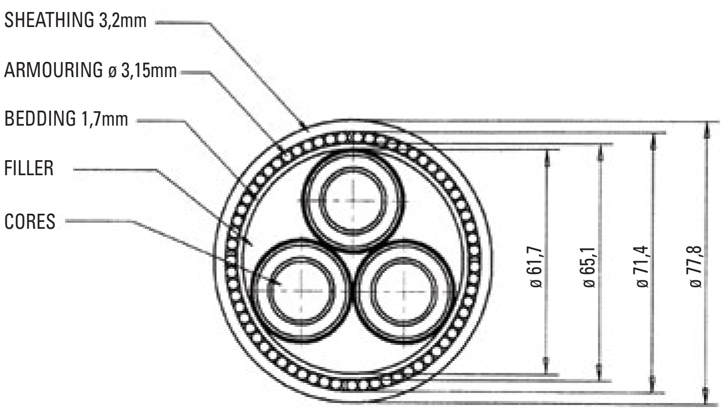

Figure 1: Cross section of the cable used for the simulations [5].

The main problem with the determination of the installed ratings of cable systems is that the engineer responsible for the cable network normally does not have general access to the methods and tools used to determine the steady state and emergency ratings of the installed cables under the varying conditions. These conditions include ambient temperature, soil temperature, soil thermal resistivities and other variables that will influence the temperature of the cable.

Although a number of FE simulation programs are freely available, it requires a good understanding of the specific program, and experience in the application of the program, to be able to do advanced thermal studies as is required for cable installations.

This article address these factors and describes a model that can be used by engineers and utility operators to determine the load (constant and variable) under which a cable can operate under non-standard installation conditions without exceeding the maximum allowable conductor temperature.

The proposed model has the benefit that utilities and municipalities would not be required to purchase the simulation program. This reduces the costs dramatically and makes it affordable for the small municipalities and clients.

The system is based on a third party providing the simulation software and other programs to perform the required actions as required by the client. The service provider will have the combined experience and knowledge of the thermal behaviour of cables as well as the required expertise in the application of the specific simulation software. The service provider will install and maintain the software on a server and will ensure that the latest versions of the software are used for the simulations.

The simulation model will be developed by the service provider based on the information supplied by the client. The information required from the client will be the type and size of the cable system and the installation conditions. The client will then be granted access to the system to determine the required ratings from a remote location which could be the office of the engineer, the control room of a utility with the knowledge of the cable operating conditions or any computer with internet access.

Figure 2 shows the basic OCRC (Online Cable Rating Calculator) model with the heart being the simulation server where the simulation software and other control programs are installed.

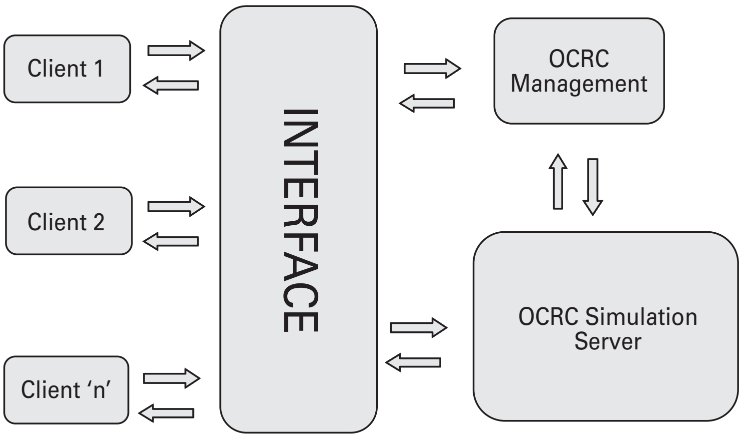

Figure 2: OCRC model structure.

Functions of units in this model

OCRC management

- Register clients and maintain licences
- Manage and maintain simulation software on the server
- Create cable installation model in conjunction with the client
- Maintain the client database
- Maintain the data libraries in the simulation program
- Client support and consultation

OCRC simulation server

- Run the Simulation Software program continuously in the background (the program will allow multiple simultaneous client access)
- Run the OCRC access software
- House all client databases
- Allow clients to log onto the OCRC Simulation Server with a Username and Password via the Internet and Service Provider website

Programme

Following registration by the client for access to OCRC, the cable model to be analysed will be created and the required expected outputs confirmed. When the client accesses the program, he will be required to select the type of simulation to be performed. Two options will be available, namely 'State Rating' and 'Emergency Rating'.

Steady state rating

For the steady state rating only basic information (values of variables) will be required based on the cable model that was created. The program will then calculate the current for the required conductor temperature using the steady state thermal simulation platform.

Emergency rating

More information will now be required to perform the calculations. The first step will be to calculate the temperature of the conductors before the emergency load is applied. It will therefore be required to input not only the basic information but also the current at which the cable operated prior to the application of the emergency current. For the emergency rating calculation it will be required to input the 'emergency' or 'overload' current for which the simulation should be performed as well as the time for which the current is expected to flow. Two outputs will be available to the client, namely: the temperature of the conductors if the 'emergency' current is maintained for the specified time, and the time that it will take for the temperature of the conductors to reach the maximum allowable temperature.

Conclusion

The client will be able to select the format in which the results should be presented. These should be the final results as for steady state simulations and tables or graphs results showing for example the increase in temperature with time for the selected conditions.

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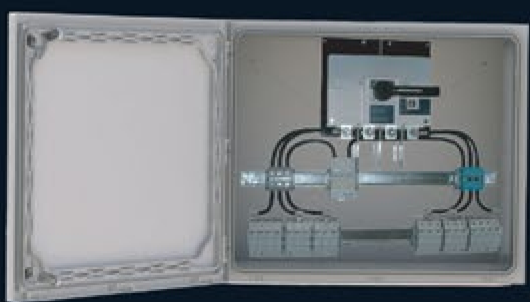

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New technologies bring new challenges, new demands and the need to review best practice. No system can be operated without adequate maintenance. A critical component of a wind energy generation system is the turbine gearbox. The techniques of assessing the condition of the gearbox and appropriate maintenance, must be understood.

Dawning of the Wind Age

SL-L Lumley, WearCheck

In 2008, more than 90% of South Africa's electricity was produced from coal, with nuclear energy making up most of the balance. Growing energy demand and concerns over the environmental impact of coal-fired power generation has led the Department of Energy (DoE) to develop several programmes – all aimed at diversifying South Africa's energy portfolio through the incorporation of renewable energy technologies.

South Africa's Integrated Resource Plan (IRP), under the leadership of the DoE, foresees renewable energy contributing 42% or 17,8 GW of the country's new generation capacity by 2030. One of the ways they plan to achieve this is with 8,4 GW of wind-generated power.

The DoE's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has already overseen the completion of four successful bidding windows, with the fourth bidding window being extended to include additional allocation under the DoE's expedited procurement process.

The 3 347 MW's worth of approved wind farm bids from all four bidding rounds will result in the construction of several wind farms over the coming years that will collectively house in the region of 1 500 wind turbines.

The estimated lifespan of wind turbines is about 20 years, compared to conventional steam turbine generator units that have averaged 40 years. The failure rate of wind turbines is about three times higher than that of conventional generators; historically this has been attributed to constantly changing loads experienced by the wind turbine as a result of environmental variants.

Owing to these highly variable operational conditions, the mechanical stress placed on wind turbines is incomparable in any other form of power generation and they consequently require a high degree of maintenance to provide cost effective and reliable power output throughout their expected 20 year life cycle. The wind turbine gearbox is the most critical component in terms of high failure rates and down time.

These premature gearbox failures are a leading maintenance expense that can substantially lower the profit margin of a wind turbine operation, as they typically result in component replacement. Despite significant advancements in gearbox design, they remain an operation and maintenance cost driver owing to the very high associated repair costs coupled with a high likelihood of failure through much of the wind turbine's life cycle.

Ensuring long-term asset reliability and achieving low operation and maintenance costs are key drivers to the economic and technical viability of wind turbines becoming a primary renewable energy source in South Africa. Oil analysis, along with other condition monitoring tools, offers the potential to effectively manage gearbox maintenance by detecting early damage as well as tracking the severity of the damage. It is for this reason that most OEMs recommend routine oil analysis as part of an effective maintenance strategy.

Figure 1: Nacelle housing gearbox and generator being hoisted during installations (courtesy of Nordex).

Routine oil analysis is one of the most widely used predictive and proactive maintenance strategies for wind turbines and utilises a test slate that evaluates the condition of the in-service lubricant and helps evaluate the condition of internal mechanical components.

Detecting abnormal wear

The fundamental concept behind monitoring wear appears uncomplicated: *Trend the metal wear rates for sudden increases that indicate a change in the system's health.*

Wear metal generation rates are often described as following a bathtub curve. The curve represents wear generated over the lifetime of a typical wearing component, with elevated wear levels during bedding-in, followed by prolonged periods of relatively constant wear levels, followed by the onset of severe wear and an exponential increase in metal generation leading to eventual failure at the end of the component's life.

Figure 2: Routine maintenance performed up-tower (courtesy Siemens).

While this is a sound theory, wear debris generation is a complex phenomenon. Wear rates can increase and decrease throughout the life time of the gearbox because of several factors such as operating loads, lubricant quality, fault progression, etc. Even during fault progression, wear rates are highly mutable depending on the microstructural material properties of the wind turbine gearbox components, for example, cylindrical roller bearings.

Commercial oil laboratories employ varying techniques when it comes to detecting (quantifying and classifying) wear particles in oil, each with its own strengths and limitations. The most widely used and OEM-requested laboratory techniques will be described.

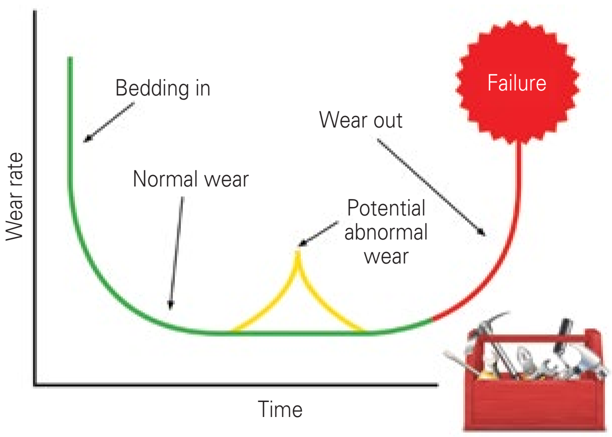

Figure 3: Bathtub curve.

Spectrometric analysis

The spectrometer is used to determine the presence and concentration of different elements in the oil. These are measured in ppm (parts per million). The measured elements are usually divided into three broad categories: Wear metals such as iron, contaminants such as silicon and oil additives such as phosphorus.

Wind turbine gear oil analysis usually requires close monitoring of iron and copper wear rates as these metals are most commonly used in the construction of internal gearbox components. In terms of wear metals detected in the oil, the iron wear rate is usually the highest reading, because almost everything in a gearbox is made from different steel alloys. Sources of iron include bearings, shafts, and gears, while copper wear usually originates from bronze alloy bearing cages.

Unfortunately the spectrometer can only measure very small particles, usually less than eight microns in size. The instrument cannot 'see' larger particles that might indicate a severe wear situation is developing.

Ferrous debris monitor

The ferrous debris monitor provides a measure of the total ferrous content of the oil sample and from this measurement the total amount of ferrous (iron) debris can be determined irrespective of the particle's size.

Wear metal particles detected by spectroscopy are typically less than eight microns in size. These small particles can be generated by rubbing wear or fretting corrosion. Larger particles are generated by more severe wear modes such as fatigue wear, pitting and spalling. These larger ferrous particles present in the used oil sample can be detected by using this method. The PQ index is not an actual concentration measurement, but it can be compared to the iron (ppm) reading obtained from the spectrometric analysis.

If the PQ index is smaller than the iron (ppm) reading, then it is unlikely that particles larger than eight microns are present. Alternately, if the PQ index increases significantly while the iron reading remains consistent, then larger ferrous particles are being generated and further analysis into the cause of the elevated PQ should be performed.

Microscopic Particle Examination (MPE)

In terms of wear particles, their morphology and quantity provide direct insight into overall gearbox health. An MPE is performed by filtering the oil through a membrane patch of a known micron rating and any debris present is examined under a microscope. The membrane patch is examined for wear, contamination and colour.

An MPE can provide clues to the source of the debris and the potential seriousness of the problem that may be causing it. Individual particles themselves are not categorised, but instead observations are recorded for trending purposes using a size and concentration reference matrix.

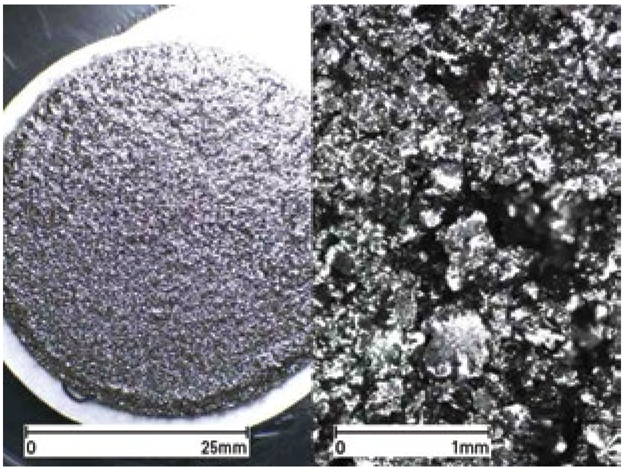

Figure 4: An MPE from a wind turbine gearbox.

Analytical ferrography

Analytical ferrography involves observing and categorising particle size, shape, colour and surface texture under magnification.

Evaluating the concentration, size, shape, composition and condition of the particles indicates where and how they were generated. The particle's composition indicates its source and the particle's shape reveals how it was generated. Abrasion, adhesion, fatigue, sliding and rolling contact wear modes each generate a characteristic particle type in terms of its shape and surface condition.

Particle composition is broken into categories that include: ferrous wear, white metal, copper and fibres. Ferrous particles can further be identified as steel, cast iron, dark oxides or red oxides (rust). A skilled analyst can also determine if metallic wear particles are caused by cutting wear versus rolling or sliding wear. Wear debris monitoring has been demonstrated to be an effective means of detecting gear and bearing fault initiation.

The main particle types related to the fatigue process encountered in wind turbine gearboxes are - laminar micro-particles (micropitting), laminar particles, chunky fatigue particles and spheres.

Analytical ferrography can be a powerful diagnostic tool in oil analysis. When implemented correctly it provides a tremendous amount of information about the machine under operation.

Cool, clean and dry

It is often said that there are three key requirements for maintaining the condition of wind turbine gear oil: keep it cool, keep it clean and keep it dry. In truth this applies to any mechanical system, but these requirements, in the context of this article, relate to the monitoring of oil degradation and contamination of wind turbines.

Detect oil degradation

The different modes and severities of oil degradation are dependent on the oil type, application and exposure to contaminants. Oil degrades over time owing to its ability to react with oxygen in the atmosphere. This process is known as oxidation. Oxidation causes the viscosity to increase and acids to form in the oil. The rate at which this occurs can be increased by high operating temperature and the presence of contaminants.

In wind turbine gearboxes, oxidation also results in metal corrosion, varnish formation, foaming/air entrainment, poor water demulsibility and filter plugging.

The following tests are usually performed on wind turbine gearbox oils to detect oil degradation and oxidation.

Kinematic Viscosity (KV)

KV is defined as a fluid's resistance to flow under gravity, at a specified temperature and this in turn determines the thickness of the oil film that prevents contact between metal surfaces. KV is measured in centistokes (cSt) and one centistoke is one millimetre squared per second. Typically, KV is reported at 40°C (KV40) and 100°C (KV100) for wind turbine gearbox oil analysis.

A lubricant has many functions to perform and these can be categorised into four fundamental groups: Reduction of wear, removal of contaminants, removal of heat and acting as a structural material. All these functions are negatively impacted if the viscosity of the oil falls outside of the intended viscosity range i.e. too high or too low. If the viscosity is not correct for the load, the oil film cannot be adequately established at the friction point. Heat and contamination are not carried away at the proper rates, and the oil cannot sufficiently protect the component.

A lubricant with the improper viscosity will lead to overheating, accelerated wear and, ultimately, failure of the component. It is for this reason that viscosity is considered the most important physical property of a lubricant.

Trending of viscosity data is important as deviations from the norm may indicate base oil degradation, additive depletion or the use of an incorrect lubricant.

When the oil's viscosity increases, it is usually because of oxidation or degradation, typically as a result of extended oil drain intervals, high operating temperatures, presence of water, or presence of other oxidation catalysts or the addition of an incorrect lubricant.

Decreases in oil viscosity are attributed to degradation of the Viscosity Index Improver (VII) additive in the oil as a result of shear or the use of an incorrect lubricant during refilling and topping-up procedures.

A low viscosity (<15% of new KV) is generally considered to be more problematic as this results in a reduced film thickness and the consequent propagation of fatigue cracks associated with micropitting. Micropitting is a surface fatigue phenomenon resulting in superficial damage that appears in high rolling contacts and is characterised by the presence of small pits on the tooth surface. They first appear in the rolling zone of the gears and then progress towards the root (dedendum) of the gear.

Micropitting causes tooth profile wear (deviations in the shape of the tooth), which increases vibration and noise, concentrates loads on smaller tooth areas increasing stress on gear teeth and shortening gear life.

Viscosity Index (VI)

The viscosity index characterises the effect of temperature on an oil's viscosity and is of particular importance in applications where operating temperatures vary significantly. The VI can change when the lubricant degrades (chemically 'breaks down') or degradation by-products accumulate. The kinematic viscosity at 40°C and 100°C are used to calculate the viscosity index.

Fourier Transform Infrared (FTIR)

Another technique employed to detect base oil oxidation is Fourier Transform Infrared (FTIR) analysis. FTIR analysis effectively measures the concentration of various organic or metallo-organic material present in the oil. When oil is oxidised, the hydrocarbon oil molecules can become restructured into soluble and insoluble oxidation by-products as a result of the sequential addition of oxygen to the base oil molecules. FTIR measures the accumulation of these by-products.

FTIR produces an infrared (IR) spectrum that is often referred to as the 'fingerprint' of the oil as it contains specific features of the chemical composition of the oil. The IR spectrum can be used to identify types of additives, trend oxidation and nitration by-products that could form as a result of high operating temperatures and thermal degradation caused by aeration/foaming. These are all important indicators of the lubricant's ability to perform its basic functions as detailed earlier on in this paper.

The usefulness of FTIR in determining oxidation is dependent on the base oil used to formulate the lubricant. Synthetic lubricants often contain ester compounds which have a significant peak in the infrared spectra area where the oxidation level for mineral oils is measured.

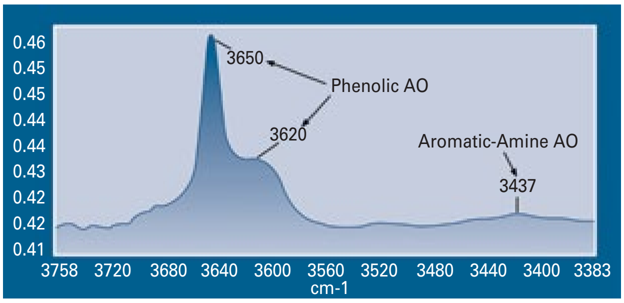

Figure 5: FTIR spectrum showing antioxidants (courtesy Noria Corporation).

Despite this, several studies performed by international oil analysis laboratories have shown a correlation between the FTIR oxidation reading of synthetic oils and other degradation parameters measured in the oil. In synthetic oils the oxidation value by FTIR in itself is not necessarily useful but trending it in conjunction with other parameters can be quite revealing.

Total Acid Number (TAN)

The TAN is a quantitative measure of acidic compounds in the oil that are generated as a result of oxidation and the formation of acidic degradation by-products.

The TAN is also utilised as a means to determine optimal drain intervals. The reasoning behind this is as follows: An increased TAN could be the result of increased oxidation and, if oxidation is a consequence of oil ageing, then it follows that the TAN could be used as an indicator of oil serviceability, as high TAN levels could indicate additive depletion (of anti-oxidant additives).

The TAN of the new oil will vary based on the base oil and additive package. As the TAN value of the oil increases, viscosity rises and the lubricating potential of the oil is compromised, leading to increased wear.

In addition, the corrosive tendencies of the oil will increase, further exacerbating component wear. Condemning limits depend on the lubricant in use and the environmental conditions in which the wind turbine will operate but, as a general rule, an increase in the TAN of more than 1mg KOH/g above the starting TAN of the new oil is considered cause for concern.

Remaining Useful Life (RULER)

A change in viscosity and TAN is usually a lagging indicator of oxidation. Despite the validity of all of these measurements, the fact remains that they all reveal damage to the base oil after it has occurred. A preferable scenario would be to evaluate the oil's ability to resist further oxidation by measuring the anti-oxidant additive reserves, in essence, its remaining useful life.

Oil oxidation is a series of chemical reactions both initiated and propagated by reactive chemicals (free-radicals) within the oil. As the oil degrades, a sequence of events occurs, each of which can be measured with oil analysis. At first, the anti-oxidant additive package depletes and then the base oil oxidises. The anti-oxidant additive is sacrificial - it is there to protect the base oil from oxidation. The most common anti-oxidant additives found in wind turbine gear oils are phenolic inhibitors, (these work to neutralise the free-radicals that cause oxidation) and aromatic amines (these work to trap free-radicals).

The RULER test is a proactive technique used for measuring anti-oxidant depletion rates and calculating the remaining useful life of the oil.

Working in the proactive domain, maintenance staff can perform a partial drain and fill or top-treat the oil to replenish the anti-oxidant concentration to avoid base oil degradation.

Likewise, for planning and scheduling purposes, RULER monitoring provides management with a significant forewarning of impending oil failure (assuming no intervention to affect the chemistry), which allows the event to be handled in such a way that cost and impact on the organisation are minimised.

It is for this reason that RULER analysis is ideally suited to monitoring wind turbine gearbox oil degradation caused by exposure to elevated temperatures and oxidation. RULER along with TAN is often utilised to establish optimal oil drain intervals.

The rate of anti-oxidant depletion versus time (anti-oxidant depletion trend) can be monitored and used to predict the right oil change intervals. The established RULER limit value for most wind turbine gear oils is 25% of the new oil value.

Detect contamination

The third major function of oil analysis is to monitor levels of contamination. Contaminants can be classified as either internal or external. Internal contaminants are generated within the mechanical system such as wear debris from gears and bearings. External contaminants are substances that exist in the environment but should not be in the oil. The most common ones are dirt, air and water. Contaminants can be directly damaging to the machinery being lubricated, dirt is abrasive and can cause components to wear abnormally; and water causes metals to rust. Contaminants can also cause the oil to degrade which, in turn, may have an adverse effect on a mechanical system.

Over the years, wind turbine manufacturers have increasingly focused on oil quality and cleanliness, which has a huge impact on the lifetime of bearings and the performance of the gearbox. This is because higher output means more strain on gears, increased mechanical wear and a greater chance of oil contamination. The three main sources of oil contamination in wind turbine gearboxes are moisture, solid particles and air (foam and entrained air). Contamination can enter gearboxes during manufacturing, be internally generated, ingested through breathers and seals, and accidentally added during maintenance.

A recent edition of the publication *Wind Power Monthly* quoted a major wind turbine gearbox manufacturer as saying that over 70% of the damage done to the gearbox was a direct result of particles and moisture contamination.

When it comes to contamination control in wind turbine gearboxes, the adage 'if you can't measure it, you can't manage it' is most apt. With that in mind, what follows is a brief description of the three most commonly encountered yet detrimental contaminants in wind turbine gearboxes.

Air contamination

Air can exist in oil in four different states: Dissolved, entrained, foam and free.

Dissolved air exists as individual molecules which are similar to carbon dioxide dissolved in carbonated soft drinks. This type of air is invisible and difficult to detect. Entrained air in oil is comprised of tiny air bubbles suspended in the oil. This type of air contamination is considered to be the most destructive and can usually be identified by the oil having a cloudy appearance. Foam is a collection of relatively large air bubbles that accumulate on or near the surface of the oil. In the free phase, there are air pockets trapped in dead zones within the mechanical system.

Foam and entrained air are the two problematic states of air contamination most experienced in wind turbine gearboxes.

Foaming and entrained air can damage lubricating oil by increasing the rate of oxidation and thermal degradation, depleting additives, reducing its heat transfer capabilities and reducing its film strength. Oil molecules oxidise when they come into contact with oxygen. That being the case, it stands to reason that an increase in entrained air results in increased exposure to oxygen which consequently causes an increase in oil oxidation.

To make matters worse, foam is also an efficient thermal insulator, so the temperature of the oil can become difficult to control. When oil runs hot, viscosity runs thin which degrades film strength in frictional zones leading to wear.

The most common causes of foaming are:

- Water contamination
- Solids contamination
- Depleted anti-foamant additive
- Mechanical issues (causing excessive aeration of the fluid i.e. low oil level)
- Overfilling of the sump in splash and bath lubricated compartments
- Cross contamination of the fluid with the wrong lubricant
- Contamination of the fluid with grease
- Over treating with anti-foamant additive

Foaming is a serious concern in wind turbine gearboxes and is generally the result of a mechanical problem or a chemical issue relating to the condition of the oil. Performing a foaming tendency and air release test can help differentiate between the two causes of foaming as described in *Figure 6*.

	Analysis	
	Air Release (ASTM D3427)	Foam Stability (ASTM D892)
Mechanical Problem (excessive aeration)	Same as new oil	Same as new oil
Air Detrainment problem (oil does not release air bubbles	Increase from new oil	Same as new oil
Depleted anti-foamant additive	Increase from new oil	Increase from new oil

Figure 6: Table on mechanical problems (courtesy Noria Corporation).

Foaming tendency is a multi-stage test used to determine the oil's tendency to entrap air and cause oil foaming as well as the ability of the oil to dissipate the foam (foam stability). The foaming tendency is the amount of foam formed on the completion of the test and the foam stability is how long it takes for the foam to collapse.

With air release, the time taken for the oil to release a specified amount of air under predetermined conditions is measured. Wind turbine gearbox oil limits for both foaming tendency and air release are dependent on the oil used.

Water contamination

Water can exist in three phases in oil: Dissolved, emulsified and free.

Different oils have different water contamination handling abilities depending on the base stock and additives used during formulation. The amount of water an oil can carry in solution is known as the saturation point. Once this point is reached, any additional water added will form an emulsion or fall out of suspension as free water.

Below saturation level, the molecules of water are dispersed alongside the oil molecules resulting in water in the oil that is not visible. This is known as dissolved water, the least dangerous water state to a lubricated system. When the amount of dissolved water exceeds the saturation point, the oil is no longer able to absorb more water, resulting in emulsified water. This is characterised by a hazy or cloudy appearance of the oil. Further increases in water content in the oil will result in separate levels of oil and water forming. This state is known as free water.

Wind turbine operators have observed that water entrainment in gearboxes can significantly degrade the gearbox lubricant by causing the lubricant to foam or lose its ability to create a sufficient film thickness for elastohydrodynamic (EHL) contact. Water contamination can also cause the formation of rust on internal components, or react with the additives in the lubricant and diminish their effectiveness. There is

Water contamination problems in wind turbine gearboxes	
Problem	**Summary**
Corrosion	Ionic currents in aqueous solution; ptiing, leakage, breakage
Additive drop-out	Polar hydrophilic additives depletion, also breaking colloidal suspensions of additive particles; loss of additives, parts fouling
Microbial growth	Colonization of oils by bacteria and/or fungi; acids, fouling slimes; health issue
Hydrolysis	Decomposition of ester-based fluids and additives; loss of oil properties, acid and sometimes gel formation
Accelerated oil oxidation	Especially if metal wear debris present, rate of oil oxidation increases by two orders of magnitude; oil thickening, acidity
Surface-initiated Fatigue Spalling	Water dissocates into O_2 and H_2 at tips of propagating cracks. H_2 migrates into and weakens stell by hydrogen embrittlement, cracks spread faster, reducing life of rolling elements, resulting in surface pits and craters

Figure 7: Water contamination problems in wind turbine gearboxes.

also the issue of accelerated wear of gearbox components by hydrogen embrittlement. Hydrogen embrittlement is the process by which various metals, including high-strength steel, become brittle and fracture following exposure to hydrogen which is part of the water molecule.

Several different techniques are used by oil analysis laboratories to determine the moisture content of lubricating oil but Karl Fisher titration is the preferred method by wind turbine gearbox manufacturers and lubricant suppliers, as even small amounts (<100 ppm) of water contamination can be detected in the oil using this method.

Through research performed by a reputable bearing manufacturer, it was found that just 1 000 ppm of water contamination could reduce ball bearing life by 70%. So in terms of condemning limits, best practice suggests maintaining water levels at or below half of the saturation level of the oil at its operating temperature. Thus, if the saturation level is 1 000 ppm at 50°C, the caution level should be set at 500 ppm, with the critical level at 1 000 ppm.

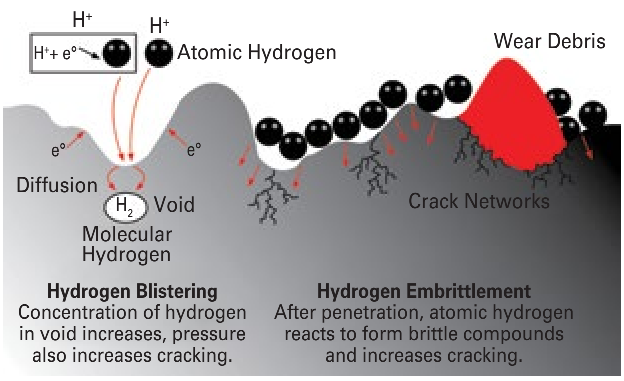

Figure 8: Hydrogen embrittlement mechanism (courtesy Noria Corporation).

Oil cleanliness

Particle counting involves measuring the cleanliness of the oil and can also be used to evaluate the effectiveness of lubricant filters.

Very much like water, particulate contamination is very damaging to wind turbine gearboxes. It is for this reason that wind turbine manufacturers have increasingly focused on oil cleanliness. Oil cleanliness is critical to establishing equipment reliability, especially as there is a direct correlation between oil cleanliness and component life.

In this technique the number of particles per millilitre of oil is counted in a variety of size ranges starting at four microns and going up to 100 microns. The total number of particles greater than four, six and 14 microns are evaluated and assigned range numbers that indicate the cleanliness of the oil.

It is particles of approximately the same size as the machine clearances that have the greatest destructive potential. Particles the size of or slightly larger than the oil film thickness enter the contact zone and damage surfaces.

While this technique is effective in determining the number and size of particles being generated, particle counting will not identify what the particles are. They could be metallic – both ferrous and non-ferrous, silica, silt, filter fibres, bacteria colonies, varnish agglomerations, water, etc.

The American Wind Energy Association and the American Gear Manufacturers Association have released a technical standard that sets attainable oil cleanliness targets [1].

Source of sample	Iso Code
Oil added to gearbox	16/14/11
Gearbox after factory test	17/15/12
Gearbox after 24-72 hour service	17/15/12
Gearbox in service	18/16/13

Figure 9: ANSI/AGMA/AWEA 6006-A01 Oil cleanliness recommendations.

With rigorous particle contamination control, bearing life can increase substantially resulting in greater gearbox reliability, uptime and energy production, extended warranty periods and a higher return on investment.

Conclusion

Oil analysis provides a solid foundation on which to build an effective condition monitoring programme in many applications. In the case of wind turbine gearboxes, oil analysis has the potential to reduce unscheduled maintenance, improve reliability and extend service life. The oil analysis tests profiled in this article can help wind farm operators get maximum value from their oil sampling programme. When these tests are performed on a routine basis and the results properly analysed, oil analysis can facilitate the maintenance of wind turbine gearboxes and, ultimately, support more widespread acceptance of this promising form of power generation in South Africa.

Reference

[1] ANSI/AGMA/AWEA 6006-A01: Design and specification of gearboxes for wind turbines.

authors

Chapter 1

Philip Lloyd

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Philip Lloyd is a Research Professor at the Cape Peninsular University of Technology (CPUT), having previously been part of the R&D team of the Chamber of Mines Research Organisation and then part of the world of international construction. He trained as a Chemical Engineer at the University of Cape Town (UCT) and as a Nuclear Physicist at the Massachusetts Institute of Technology (MIT). He has won a number of awards, including a SANEA Award in 2010.

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Celine Paton is an Independent Contractor for the Energy & Environment (E&E) team at Frost & Sullivan Africa. She has over four years' energy advisory expertise in addition to five years' investment banking (project finance) experience at a renowned European bank. Celine holds a BBusSc in Management and a Master of Commerce in Business Economics from the Universite Catholique de Louvain and the Katholieke Universiteit Leuven in Belgium.

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Antony English holds a BSc Engineering (Electro-Mechanical) from the University of Cape Town (UCT) and an MBA from the Gordon Institute of Business Science (University of Pretoria). As the chief designer and co-founder in Freedom Won, he is an innovator in Africa in the implementation of electric mobility solutions. Antony (and his team at Freedom Won), has developed a wide range of energy storage solutions for renewable energy and battery back-up systems, using lithium batteries. Antony is photographed with Freedom-Won co-founder, Lizette Kriel.

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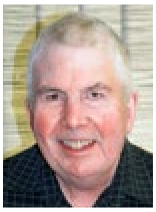

Glyn Craig

Techlyn

Glyn Craig spent his formative years in a small town in the KZN midlands. The town had its own power station where his father was the engineer in charge. The station was basically wood-fired, with timber grown sustainably on extensive municipal estates. This resulted in Glyn's early decision to pursue a career in engineering. After completing his schooling, he joined the South African Broadcasting Corporation (SABC) as a trainee and was later awarded a bursary to study at the newly established Wits Technikon. The course was RF oriented but broadly based with courses in applied mechanics, physics and heavy current electricity. Apart from imparting theoretical concepts, the course stressed practical knowledge including mechanical work. After completing the course, Glyn was posted to the SABC's Bloemendal transmitting station near Henly-on-Klip where he worked on high power (250 kW) shortwave transmitters. While running an electronics and mechanical department in a mining research laboratory, Glyn studied and completed the Government Certificate of Competency (GCC) by correspondence. The mechanical subjects were to prove valuable when he founded Techlyn in 1985.

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Philip Venn is the Engineering Manager for the Packaged Gases division at Air Products South Africa. Philip has been with Air Products for more than 25 years. After gaining his apprenticeship as a Fitter and Turner through General Electric (GE), Philip joined Air Products in 1990 as an Engineering Technician in the company's Advanced Research and Development department. After five years he was promoted to Senior Technician, and then to the position of Maintenance Supervisor. During this time, Philip qualified as an electrician and later obtained a Management Diploma from the University of South Africa (UNISA). Philip was appointed Acting Project Manager in 2010 and Bulk Engineering Manager until the end of 2014 when he was appointed to his current position.

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Chapter 2

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Energy Cybernetics

Currently employed by Energy Cybernetics, Izelle Bosman joined the North-West University in the Energy Management field in 2003 while doing her Masters degree in Mechanical Engineering. Since 2005 she has been lecturing in Energy Management to post-graduate engineering students at the University. She also presents international training short courses to working engineers. Since 2012 she has been head of the Training Division called the Energy Training Foundation (EnTF). EnTF presents international qualifications in the Energy field and has the sole licence from the US-based Association of Energy Engineers (AEE) to present the courses in Southern Africa.

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Yolanda de Lange holds the position of business development manager at the Port Elizabeth office of the Energy Training Foundation (EnTF). She is a member of the SAEE and MVPCSA. She has a Diploma in Journalism, and has been working in the energy industry since 1995. She has been involved in the SAEE since its inception in 2001/2. She was involved in the ESCO association, the Profibus Association set-up, developed the SABS0142 Wiring Committee compliance handbook, and compiled the first two editions of the Energy Efficiency Made Simple Handbook. Yolanda was the editor of Sparks Electrical News for two years and editor of Electricity+Control for 10 years. She has co-authored numerous research papers which have been presented at conferences. She manages the largest energy-related database in South Africa.

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Chapter 3

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Consultant

Andrew Murray is a consulting food process engineer and a Certified Energy Manager (CEM). He specialises in feasibility studies and design of plant for dairy, fruit processing, canning and other sectors of the food and beverage industries. He is particularly involved in energy analysis and auditing of the hygienic design of equipment and premises. For ten years he was a part time lecturer in the Department of Food Science at the University of Pretoria and has conducted more than twenty-five short courses in various aspects of food engineering and sanitary design. Prior to forming his own consultancy in 1985, Andrew held positions with the APV group and with Ceres Fruitgrowers Cooperative where he was responsible for the setting up of their first juice concentration plant. He is a member of the SA Institution of Chemical Engineers and a fellow of the SA Institute of Agricultural Engineers.

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Evert Swanepoel
Copper Development Association Africa (CDAA)

Evert Swanepoel is Centre Director for the Copper Development Association Africa (CDAA) - responsible for promoting and expanding the use of copper in Africa. His vast experience in managing large businesses has provided him with the skill and knowledge to promote copper projects that are positioned to increase the demand and utilisation of this ductile metal throughout Africa. He aims to expand CDAA membership throughout the continent to include the complete spectrum of the copper industry, from primary through to downstream companies and service organisations.

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Natalie Liddle
Thermon South Africa

Natalie Liddle holds a BTech in Marketing Management from the Cape Peninsula University of Technology. She is responsible for PR and Marketing Communications at Thermon South Africa, formerly unitemp, specialists in industrial heating, measurement and control solutions. With 10 years' experience in industrial B2B marketing, she has written many technical papers with the purpose of educating the 'non-experts' about specialist heating and measurement technologies.

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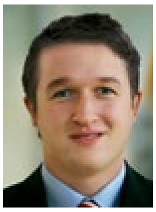
Chapter 4



Tobias Kerschensteiner
DEHN+SÖHNE

Tobias Kerschensteiner joined DEHN+SÖHNE as an apprentice electronic technician for devices and systems with a focus on test and measurement technology in 2007. In 2010 he provided technical support for safety equipment, lightning and surge protection. In 2014 he undertook an Open University course at DAA-Technikum and became a state-registered electrician with a focus on power engineering and process automation. He is currently Key Accounts Manager for utilities at the company.

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Markus Wiersch
DEHN+SÖHNE

Markus Wiersch has an MBA and a Diploma in Mechanical Engineering. First he worked as an aircraft mechanic for the German Air Force. After his studies he joined E-T-A Elektrotechnische Apparate GmbH in product development, later becoming a project manager and finally a business area manager. He is currently responsible for Smart Energy in the division Solution Management at DEHN+SÖHNE.

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Tim Craven
H3iSquared

Tim Craven joined H3iSquared in 2008 in a technical support role and has been with the company since then, providing technical support, network auditing and training to leaders in the industrial, utility and ITS industries.

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Chapter 5

Henni Scholtz
Aberdare Cables

Henni Scholtz is currently the General Manager for Product Development and Application at Aberdare Cables. Prior to this, he held positions of Technical Manager and Technology Development Manager within the organisation. Henni worked as an engineer and EIT for Eskom Projects and Generation at Koeberg, Kendal and Duvha power stations over a period of 10 years, and for Voltex Manufacturing as a production engineer within its cable division. He holds a B Eng (Mech) degree from the University of Stellenbosch and is a registered Pr Eng (ECSA) and a member of the AECMSA TSC committee, the SANS TC66 electric cables committee and IEC TC20 WG 17.

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Professor Jerry Walker
Walmet Technologies

Professor JJ (Jerry) Walker started his career as an Apprentice Millwright at Iscor Vanderbijlpark and completed a National Higher Diploma in Engineering (Electrical) at the Vaal Triangle Technikon in 1986. In 1993, after spending almost 23 years in industry, he joined the Vaal Triangle Technikon (now known as Vaal University of Technology or VUT) as a lecturer in the Department of Power Engineering. He completed a BTech degree in 1996. He embarked on post graduate studies in 1997, specialising in diagnostic testing of XLPE-insulated cables. He completed a DTech degree in 2004 at VUT. He was appointed Associate Professor and Head of the Institute for High Voltage Studies at VUT in 2005. He retired from the VUT in 2006. He is currently Director of his own company, Walmet Technologies. He is a Visiting Professor at VUT, managing research and post graduate supervision in power engineering.

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Taryn Becker,
Walmet Technologies

Taryn Becker started her studies at the Vaal University of Technology (VUT) in 2009. She completed the National Diploma in 2011 and graduated in 2014 with a BTech in Electrical Engineering (Heavy Current). She joined Walmet Technologies in January 2014.

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Steven Lara-Lee Lumley
WearCheck

Steven Lara-Lee Lumley is in charge of technical development for condition monitoring specialists WearCheck. Steven holds an N6 mechanical engineering diploma (HND N6). She joined WearCheck in 2008 as a diagnostician, and worked her way up to the position of senior diagnostician. She was later promoted to the position of Lead – technical development. Steven, who diagnosed her millionth sample during 2014, has run customer training courses on oil analysis for WearCheck customers in Dubai and India, and one of the recent focus areas of her work has been the development of condition monitoring programmes for wind turbines. She received the prestigious South African Institute of Tribology (SAIT) prize for Best Technical Presentation Award 2014, for her presentation entitled: The role of oil analysis in wind turbine gearbox reliability given at their Oil Analysis seminar in 2014.

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Abbreviations

A

- ADB - African Development Bank
- AEE - Association of Energy Engineers
- APC - Ambient Proportional Control
- ARP - Address Resolution Protocol
- ATIA - African Trade Insurance Agency

C

- CAPEX - Capital Expenditure
- CCTV - Closed Circuit Television
- CDAA - Copper Development Association Africa
- CDD - Cooling Degree Days
- CEM - Certified Energy Manager
- CEMS - Continuous Emissions Monitoring Systems
- CI - Circuit Interruption
- CIFI - Circuit Interruption Fuse Integrated
- CMVP - Certified Measurement and Verification Professional
- CPC - Continuing Professional Competency
- CPU - Central Processing Unit
- CPU - Central Processing Unit
- CSP - Concentrated (or Concentrating) Solar Power

D

- DFR - Dynamic Finite Rating
- DNA - Deoxyribonucleic Acid
- DOL - Direct Online
- DST - Department of Science and Technology

E

- ECA - Electrochemically Activated
- ECM - Energy Conservation Measure
- ECSA - Engineering Council of South Africa
- EMI - Electromagnetic Interference
- EMO - Energy Management Opportunity
- EnTF - Energy Training Foundation
- EV - Electric Vehicle
- EVO - Efficiency Valuation Organisation

F

- FE - Finite Element
- FTIR - Fourier Transform Infrared
- FTP - File Transfer Protocol

G

- GDP - Gross Domestic Product
- GOOSE - Generic Object Oriented Substation Event
- GPS - Global Positioning System

H

- HAI - Hospital Acquired Infection
- HDD - Heating Degree Days
- HHP - High Hydrostatic Pressure
- HPP - High Pressure Processing
- HSR - High-availability Seamless Redundancy
- HTTP - Hyper Text Transfer Protocol
- HVAC - Heating, Ventilation, Air Conditioning

I

- IBRD - International Bank for Reconstruction and Development
- ICMP - Internet Control Message Protocol
- ICU - Intensive Care Unit
- IDA - International Development Association (World Bank)
- IFC - International Finance Corporation
- IMF - International Monetary Fund
- IP - Internet Protocol
- IPP - Independent Power Producer
- IRENA - International Renewable Energy Agency
- IRP - Integrated Resource Plan
- ISO - International Standards Organisation
- IV - Intravenous

K

- KV - Kinematic Viscosity

L

- LCD - Liquid Crystal Display
- LED - Light Emitting Diode
- LEMP - Lightning Electromagnetic Pulse
- LPS - Lightning Protection System

M

- MEA - Membrane Electrode Assembly
- MIB - Management Information Base
- MIGA - Multilateral Investment Guarantee Agency (of the World Bank)
- MPE - Microscopic Particle Examination
- M&V - Measurement & Verification

N

- NASA - National Aeronautics and Space Administration
- NERSA - National Energy Regulator
- NMS - Network Management System
- NPV - Net Present Value

O

- OCRC - Online Cable Rating Calculator
- OEM - Original Equipment Manufacturer
- OPEX - Operational Expenditure

P

- PEF - Pulsed Electric Field
- PEM - Proton Exchange membrane
- PF - Power Factor
- PLC - Programmable Logic Controller
- PM - Permanent Magnet
- PPA - Power Purchase Agreement
- PRP - Parallel Redundancy Protocol
- PTP - Precision Time Protocol
- PV - Photovoltaic

R

- RE - Renewable Energy
- REFIT - Renewable Energy Feed-in Tariff
- REIPPPP - Renewable Energy Independent Power Producer Procurement Programme
- ROI - Rate Of Exchange
- RSTP - Rapid Spanning Tree Protocol
- RULER - Remaining Useful Life

S

- Sacci - South African Chamber of Commerce and Industry
- SAPP - Southern African Power Pool
- SCADA - Supervisory Control and Data Acquisition
- SEMP - Switching Electromagnetic Pulse
- SNMP - Simple Network Management Protocol

T

- TAN - Total Acid Number
- TECH4RED - Technology for Rural Education & Development
- TOV - Temporary Overvoltage

U

- UHP - Ultra High Pressure
- UV - Ultraviolet

V

- V - Volt
- VFD - Variable Speed Drive
- VI - Viscosity Index
- VLAN - Virtual Land Area Network
- VoIP - Voice-over Internet Protocol
- VPN - Virtual Private Network
- VRRP - Virtual Router Redundancy Protocol

W

- W - Watt
- WAN - Wide Area Network

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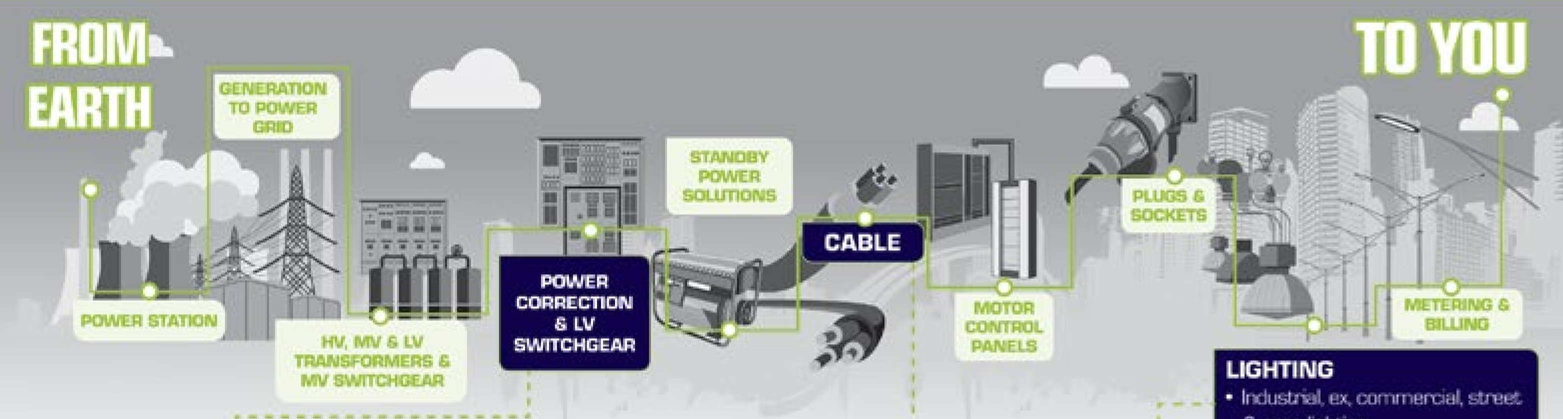

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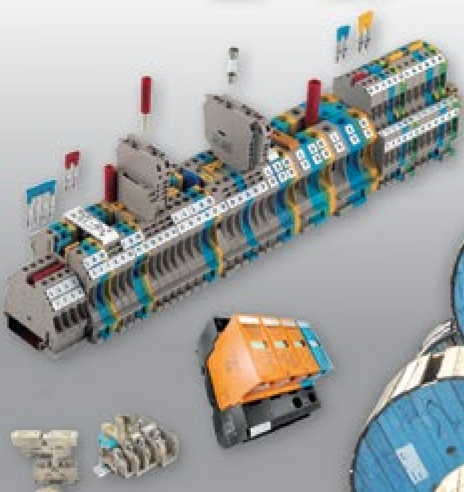

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