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Renewable Energy for a Greener Future

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Tel: 011-2696771
Fax: 011-2694754
E-mail: vidurava@nsf.gov.lk

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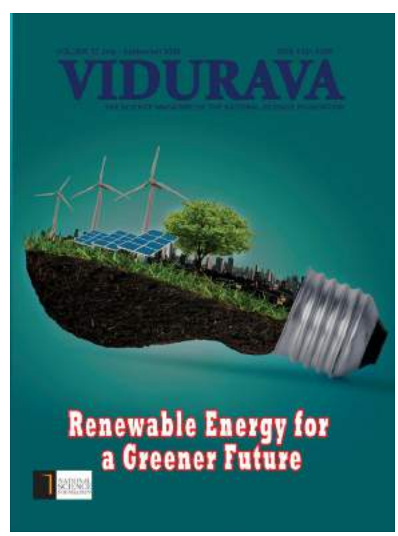

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Editorial

Renewable and Other Alternative Sources of Energy – Reminiscence of a By-gone Era

The current issue of Vidurava takes the traditional clientele of the science magazine on a thought-provoking mission on the technicalities of both renewable and non-renewable energy generation. However, rather than getting entangled in a review of these excellent presentations, it was considered prudent to reminisce on a selected few of events that were extraordinarily significant and unprecedentedly controversial, that lit up the renewable energy generation sector of Sri Lanka in the early 1980's. The information reproduced here for the benefit of our new generation, was derived from a Memoir compiled by the current writer in October 1993, and published by Natural Resources, Energy and Science Authority (NARESA), (predecessor of the National Science Foundation), to commemorate the Silver Jubilee Anniversary of the organization.

In 1980, the National Science Council, (the earliest predecessor of NSF), decided to establish a non-formal body called the "Solar Energy Group" (SEG) on the recommendation of a specialist panel on Physical and Engineering Sciences. The same year, the 'Science and Technology Information Centre' of the National Science Council established the "Renewable Energy Resources Information Service", in order to enable interested scientists and technologists to retrieve the most recent information on Solar, Wind, Biomass and Ocean Thermal Energy Conversion (OTEC) Energy sources.

In 1981, on the request of His Excellency the President, the National Science Council appointed a sub-committee to examine a proposal for a feasibility study on OTEC, submitted by Dr. Arthur C. Clark, the well known science fiction writer on space travel. It was his contention that the coastal belt of Sri Lanka in the neighborhood of Trincomalee, where the coastal sea bed drops sharply down to a depth exceeding one kilometer, provided the ideal conditions for the establishment of an OTEC power generation plant. This sub-committee assessed the materials and financial resources available for an experimental project, and decided to call for quotations from foreign agencies for the supply of materials and equipment, in order to prepare an estimate for the project. However, in the meantime, learning from the experiences and outcomes of similar experimental projects elsewhere in the world, especially in relation to the safe management, sustenance and maintenance of a massive steel tunnel meant to draw heated deep sea water to the surface from depths exceeding a kilometer for energy conversion, it was decided to abandon the exercise.

The year 1982 marked the occurrence of one of the most controversial episodes in the history of alternate energy generation in Sri Lanka. This happened when the then Minister in Charge of Power and Energy obtained Cabinet approval to establish an Atomic Energy Power Generation Plant in Sri Lanka. This surprisingly unforeseen and outrageous move in obtaining Cabinet approval for such a project came as a 'bolt from the blues' causing in the process an unprecedented uproar, and widespread public protests, demonstrations and processions. It led to serious agitation amongst the scientific community and environmentalis, who demanded a Commission of Inquiry. Responding to these public concerns, the then Head of State referred the matter to NARESA for a resolution after conducting a proper public inquiry. Consequently, the Board of Management of NARESA appointed a specialist Commission of Inquiry with the Late Prof. J.D. Gunawardena as the Chairman, and comprising some of the most experienced and highly qualified scientists and technologists in the country. The present writer functioned as the Convener and Secretary of this Commission.

The deliberations of this Commission of Inquiry took nearly two years to complete, during which the evidence and views of both local and foreign specialists were recorded. Finally the recommendations of the Commission were submitted to the Head of State. One of the key recommendations of the Commission was that, although the possibility exists for the establishment of an Atomic Energy Power Plant in Sri Lanka, the preliminary preparations including training of a workforce with the required expertise, skills and high level of discipline, was expected to take more than 20 years. With this finding, the controversial Cabinet decision was rescinded and the subject was shelved.

M. Asoka T. De Silva

Energy in the Modern World

Prof. J.B. Ekanayake

The modern society is highly dependant on an adequate supply of energy that is needed for cooking, heating, cooling, lighting, etc. At present most of the energy comes from fossil fuels such as coal, oil and gas. Over the last 25 years, the world demand for energy has grown continuously at a rate of increase of around 2.5 percent per year. This increase in consumption cannot be sustained indefinitely both because of depletion of reserves, and more urgently, because of the environmental impact of burning fossil fuels. At some time in the future the costs of extraction of oil and gas will become so high as to limit their use. Further, there is clear agreement among climate scientists that burning fossil fuels and the consequent emission of CO_2 into the atmosphere is leading to extensive climate change. Therefore, most governments are taking strenuous efforts to introduce renewable energy sources as these do not produce CO_2 during their operation and as these will not get depleted like fossil fuel.

The use of renewable energy has an important part to play in the future supply of energy and in the transition to a more sustainable energy economy. However, renewable energy has its own challenges. In general, the initial capital cost of renewable energy schemes is high and their output depends completely on the resource, and so varies with the strength of the sun and wind.

The Need for Renewable Energy

Burning fossil fuels lead to local environmental impacts such as air pollution, regional effects such as acid rain as well as the global impact on climate change.

Thermal power stations, internal

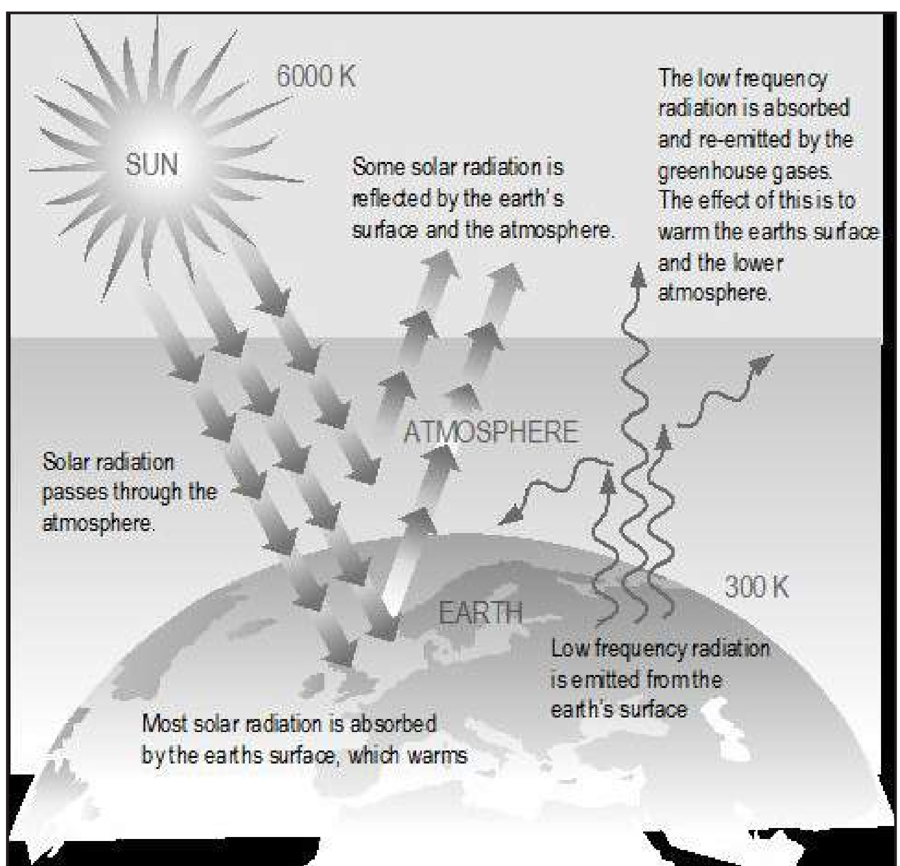


Figure 01 : Simple representation of the Greenhouse effect

Figure 02 : Wind farm (RichardJones/BusinessVisual Rights Managed)

combustion engines and building heating systems all produce gaseous emissions and very small particles that can be damaging to environment and human health. Examples of the local consequences of such emissions are the photo-chemical smogs that occur in some large cities, due to vehicle exhausts. Further, burning coal in power stations produces sulphur dioxide (SO_2) and other pollutants that lead to acid rain causing considerable environmental damage, particularly to lakes and forests.

There is a clear scientific consensus that the earth's climate is being changed by human activity through the emission of greenhouse gases. The main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NO_X) and fluorocarbons. Water vapour also plays a major role in the greenhouse effect. The greenhouse effect is a complicated phenomenon with important impacts of gases and particles in the atmosphere that can both increase or lower the earth's temperature. However, it can be understood simply as the effect of gases in the upper atmosphere absorbing the long wavelength radiation that is emitted from the earth's surface (Figure 1). The sun is a high temperature source with an effective temperature at its outer surface of around 6000 K. It emits short wavelength (high frequency) radiation that passes through the earth's atmosphere. This radiation strikes the earth, warming it, and the earth then re-radiates long wavelength (low frequency) radiation from its lower surface temperature. The high frequency radiation from the sun passes through the earth's atmosphere largely unaffected while the concentration of gases in the upper atmosphere leads to absorption of the lower frequency (longer wavelength) radiation. The temperature of the earth depends on the balance between the incoming high frequency radiation from the sun and the lower frequency radiation re-radiated from the earth's surface. Due to increasing of the concentration of greenhouse gases in the atmosphere, more of the low frequency radiation is trapped and so the temperature of the earth increases. The concentration of existing greenhouse gases in the earth's atmosphere causes the temperature of the earth to be maintained at a level suitable for life, without it the earth would be colder by some 30 ^{o}C. By increasing the concentration of greenhouse gases, as we are currently doing, the earth's temperature increases, and the climate is changed. Although an increase in average temperature has significant implications, the consequent effects such as melting of the ice in the Arctic and increases in frequency of extreme weather events are potentially even more serious. Greenhouse gases disperse throughout the earth's atmosphere and so the effect is global.

Figure 03 : Solar photovoltaic farm (RichardJones/BusinessVisual Rights Managed)

Carbon dioxide is an inevitable product of burning fossil fuels and once emitted it remains in the atmosphere for up to 100 years. It is one of the most important greenhouse gases and many countries have policies to reduce emissions of CO_2, particularly from electricity generation. By restricting the emission of CO_2 and other greenhouse gases it is hoped to limit the rise in global mean surface temperature rise to 2 °C. A rise of this magnitude with the associated increase in extreme weather events will have important consequences for agriculture and biodiversity. Allowing the continued emission of CO_2 from an electrical power sector that relies predominantly on burning fossil fuels significantly increases the risk of affecting climate change.

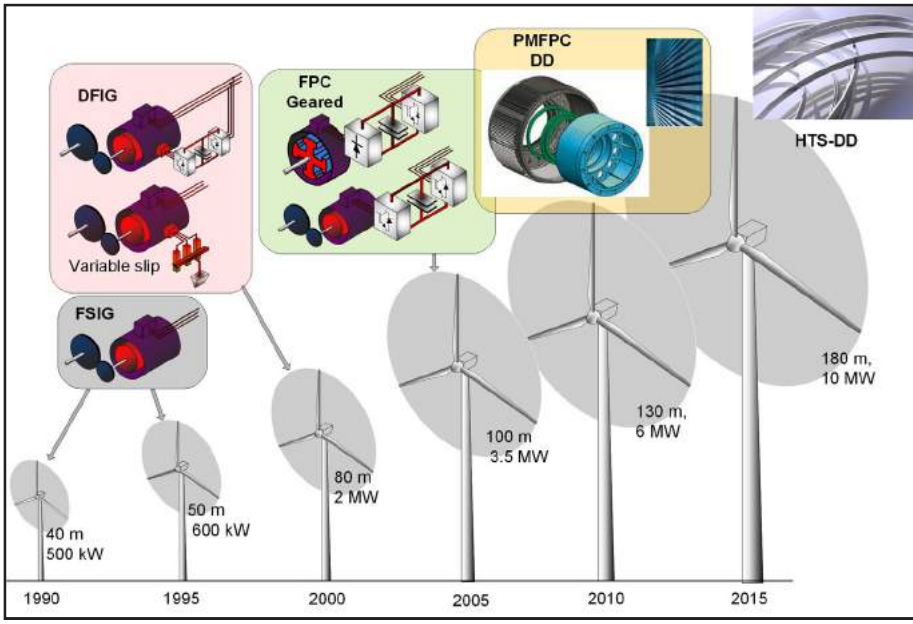


Figure 04 : Evolution of wind turbine technology

Low Carbon Electricity Generation

Climate change brought about by the emission of CO_2 from burning fossil fuels is a major driver of energy policy in many countries. Thus, alternatives to burning fossil fuel, particularly coal, are needed urgently. The options to generate electricity without emitting CO_2 are restricted to renewable energy, nuclear energy, and fossil fuel generators equipped with carbon capture and storage

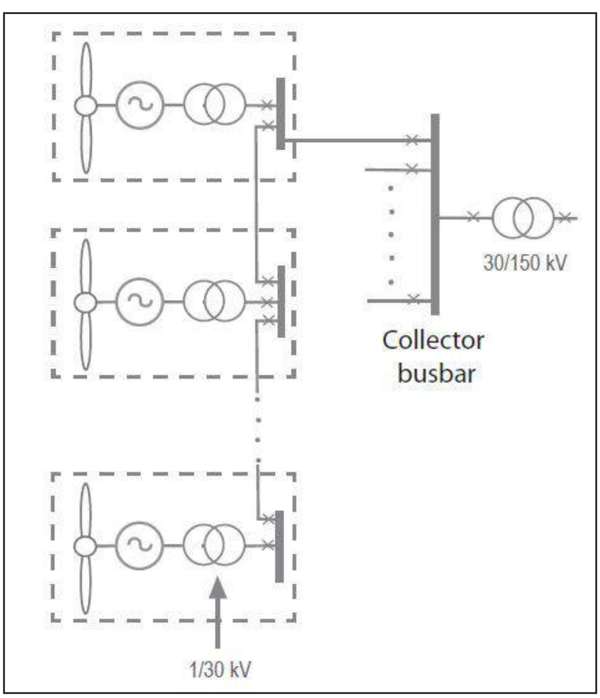


Figure 05 : Typical on-shore wind farm connection

There are those who consider that the generation of electrical energy from nuclear fission is an attractive technology and that nuclear generation should be expanded. However, nuclear generation of electricity has a number of considerable difficulties including high capital costs and continuing uncertainty over the disposal of nuclear waste.

Removing carbon either before or after fossil fuels are burnt and storing CO_2 underground has the obvious attraction that fairly conventional generating units can continue to be used. This is known as Carbon Capture and Storage (CCS). However, neither the technology for extracting the carbon from fossil fuel or storing the CO_2 has yet been demonstrated at commercial scale.

Due to limitation of many low carbon technologies, most governments encourage the development of renewable energy generation. As a stimulus of emerging renewable energy technologies, financial mechanisms such as net-metering, feed-in-tariffs, quota requirements, carbon trading or carbon taxes are introduced. Established technologies include wind power, micro-hydro, solar photo-voltaic systems, landfill gas, energy from municipal waste, biomass and geothermal generation. Emerging technologies include tidal stream, wave-power and solar thermal generation.

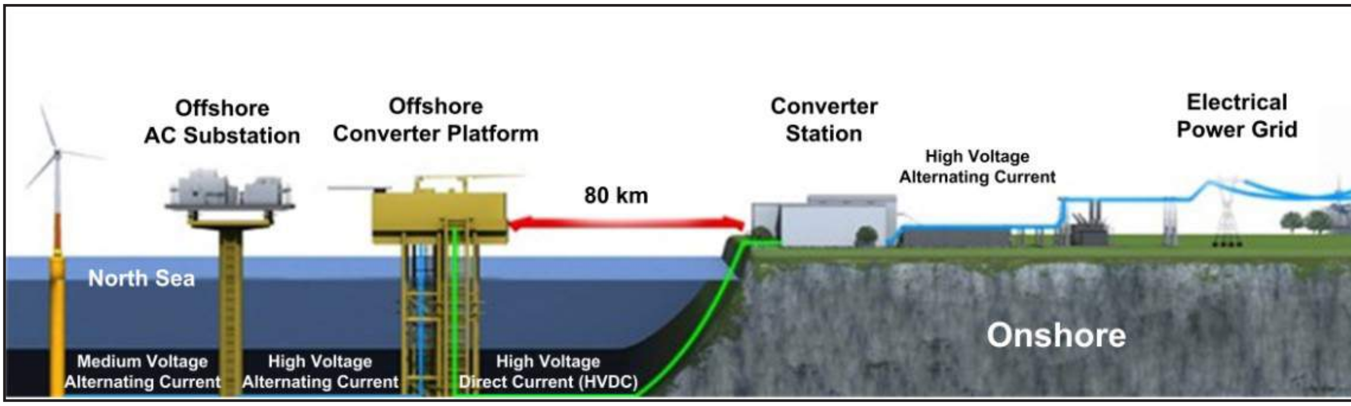


Figure 06 : Offshore wind farm dc connection

Renewable energy sources have a much lower energy density than fossil fuels and so the generation plants are smaller and geographically widely spread. For example, wind farms must be located in windy areas while biomass plants are usually of limited size due to the cost of transporting fuel with relatively low energy density. These smaller plants, typically of less than 50-100 MW in capacity, are then connected into the distribution system. In many countries the renewable generation plants are not planned by the utility but are developed by entrepreneurs and are not centrally despatched but generate whenever the energy source is available.

Figures 2 and 3 show a wind and solar energy plant sited on the hills above a former coal mining area of South Wales of the UK. The environmental impact of the schemes are limited and the land continues to be used for grazing sheep.

Energy from Wind

Wind technology is emerging as one of the more cost effective of the Renewables. There are some 597,000 MW of wind turbines installed world-wide. The advantages of wind energy generation are: each wind turbine is comparatively large (up to 5 MW onshore and up to 10 MW offshore). Once planning

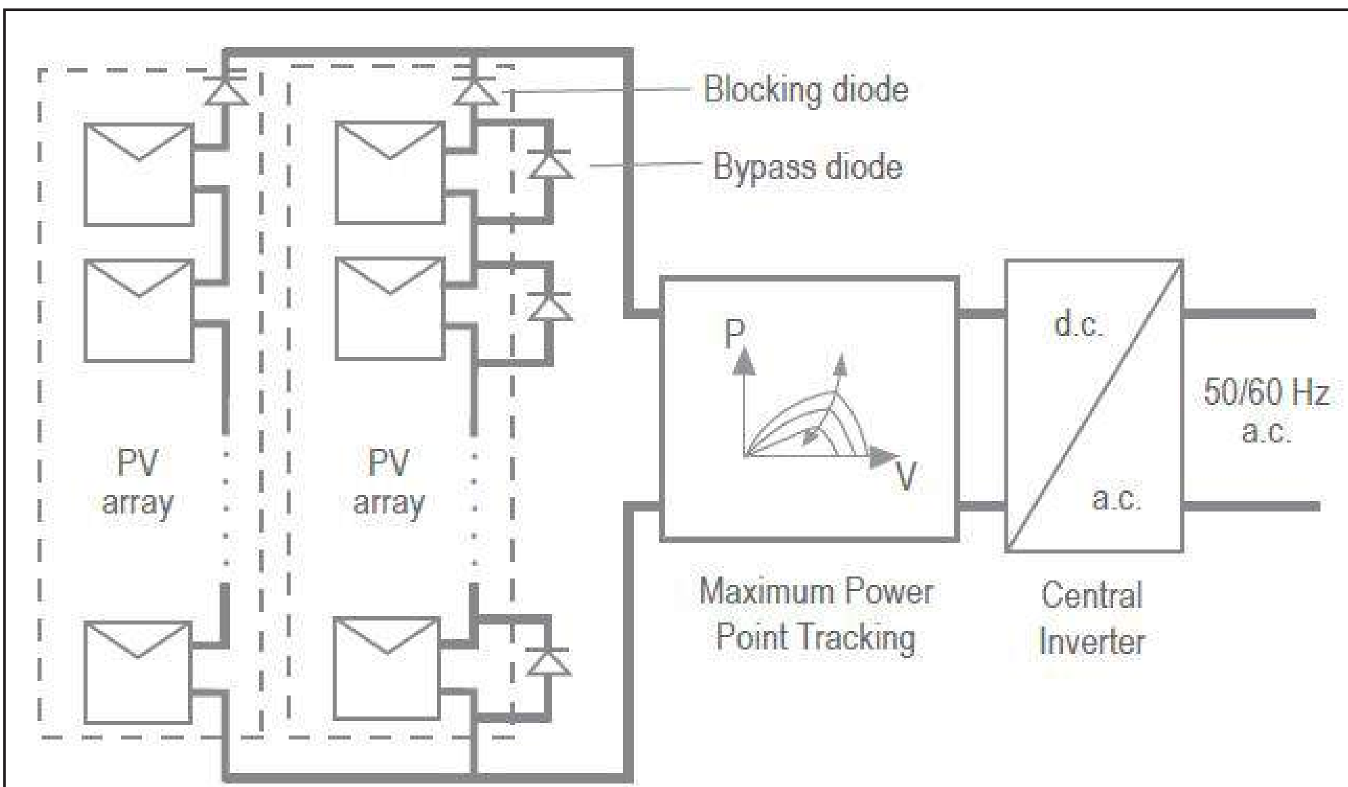


Figure 07 : PV panels connected to a central inverter

permission is obtained, wind farms can be constructed quickly and in high wind speed sites at low cost. Disadvantages are visual impact, of the intermittent energy source.

Depending on the power rating, different wind turbine topologies are used (Figure 4). They can be broadly categorised as fixed speed wind turbines and variable speed wind turbines. In a fixed speed wind turbine, a gearbox is connected in between the low speed shaft and the generator shaft (shown as FSIG). With variable speed operation, it is possible in principle, to increase the energy captured by the aerodynamic rotor. However, it is then necessary to de-couple the speed of the rotor from the frequency of the network through some form of power electronic converter. Variable speed technologies available are, doubly fed induction generator (DFIG), full power converter (FPC) with a gearbox, permanent magnet generator based full power converter direct drive (PMFPC DD), and high temperature superconductor generator based direct drive (HTS DD).

Wind turbines generate at a relatively low voltage, usually below 1000 V. Some larger turbines (>3 MW) use a higher generator voltage, up to around 3-5 kV. With these generator voltages it is necessary for each turbine to have an individual transformer either within or adjacent to the tower. This increases the voltage for connection to the power collection network, for example to 33 kV. A typical onshore wind farm connection is shown in Figure 5. A number of strings of wind turbines are connected to the collector busbar at 33 kV. A central wind farm transformer steps up the voltage to 132 kV or 220 kV for connection to the public network.

An offshore wind farm can be connected to the onshore network through an ac or a dc submarine cable. The choice of ac or dc depends on the distance to shore and the power of the wind farm. For cable route lengths above 80 km, dc transmission (Figure 6) becomes cost effective. Above around 100 km and 50 MW only dc transmission is possible due to the high reactive power generated by the capacitance of ac cables. For wind farms larger than 200 MW, dc is attractive as fewer cables are needed to connect the wind farm to shore and so multiple cables crossing a beach can be avoided.

Solar Energy

Energy from sun strikes the earth as packets of light energy, termed photons. There are two main methods of converting sunlight into electricity. Heat in sunlight can produce and drive a steam turbine to produce electricity. However, the most common technique is direct conversion of solar energy into electricity which is called Photovoltaic energy (PV). When designing a PV system, detail consideration should be given to solar resource at the site, conversion equipment – solar modules, energy storage equipment – battery, system control and loads or end – user equipment.

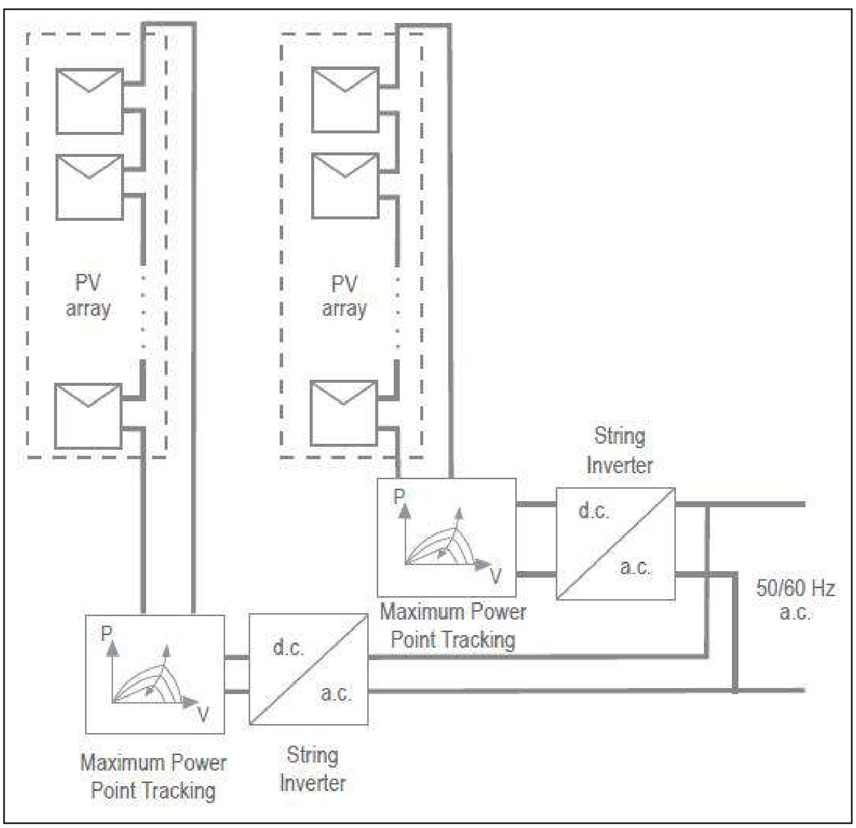


Figure 08 : String of PV panels connected to a number of string inverters

A photovoltaic cell is a device that converts energy from the sun to dc electricity by the photovoltaic effect. The cell is formed by a p-n junction. When the junction is exposed to light, dc electricity is produced from the junction. An individual cell produces an open circuit voltage of about 0.6 V. Therefore, in practical applications a number of cells are connected in series to obtain higher open circuit voltage. The short circuit current can be increased by connecting a number of cells in parallel to form a higher power and larger module. The module is the basic building block of a PV array. PV arrays are formed by connecting strings of modules in different formations. Commonly used topologies are strings connected in parallel to a central inverter, strings connected through multiple inverters, and individual modules connected through micro-inverters.

The connection of a PV array into a central inverter is shown in Figure 7. Each PV string is connected in parallel through a blocking diode. These diodes are used to prevent reverse current flowing from one string into another. Even though the central inverter connection can be cost effective, the lifetime of the central inverter is often less than that of the PV modules thus requiring its replacement at least once over the life of the solar array, adding significant cost.

Figure 8 shows the use of string inverters. Each string of modules is connected through a dc/ac converter, which allows the Maximum Power Point of each PV string to be optimized. The PV system can be expanded easily by installing additional strings of modules and their own inverters. PV modules can also be connected such that each PV panel has a micro-inverter of 150-300 W. The micro-inverters convert dc to ac from each module and their output is connected in parallel to form an array. Even though this scheme is attractive in terms of performance (unlike the other scheme the performance does not depend on the poorest module), the main disadvantage of this scheme is high cost.

Smart Grid

Modern electrical power systems, which have been developed over the last 70 years, feed electrical power generated by large central generators up through generator transformers to a high voltage interconnected transmission network. The transmission system is used to transport the electrical power, sometimes over considerable distances, and it is then extracted and passed down through a series of distribution transformers to final circuits for delivery to the customers.

From around 1990 there has been a revival of interest in connecting renewable generation to the electrical power network, which demands some degree of integration, automation and control. Electrical energy supplies that are low or zero-carbon, secure and not dependent on imported fossil fuel require demand side initiatives that include energy transactions, demand response which enables loads, and distributed energy resources to provide capacity, peak shaving and other ancillary services. In addition, services such as customer billing, management of customer equipment, and energy information, and customer empowerment are now being developed by a variety of potential providers. Delivering these services from the demand side requires communication and information technologies that are open and flexible.

Recently, the name "Smart Grid" has become common to describe this future power network. The concept is gaining a lot of traction as a means of decarbonising the power sector, allowing more renewable energy to be connected, maximising utilisation of transmission networks that have plenty of redundancy/capacity, and enabling customer participation to improve power system efficiency, security and operation. It is anticipated that with the realisation of the Smart Grid, it is possible to operate the power system with a high proportion of renewable generation.

Note : Some information are extracted from one of author's books "Renewable Energy Engineering", Cambridge University Press.

Prof. J.B. Ekanayake
Chair Professor
Department of Electrical and Electronic Engineering,
Faculty of Engineering,
University of Peradeniya
jbe@ee.pdn.ac.lk

Control of Powered Motion: The Unsung Driver of Human Civilization through Harnessing of Renewable Energy

Dr M.P.B. Ekanayake

What makes it possible for the human civilization to advance through the ages? The answers to this question may differ from expert to expert depending on their specialization. However, one can always identify a unique technological innovation which distinguishes the stages of human civilization. Anthropologists identify the discovery/innovation of stone tools, fire and wheel as earliest events which paved the way to human civilization. All these discoveries and innovations which shaped human civilization were fundamentally footed on the mastery of not only "harnessing" but also "controlling" the resources and energies already present in nature.

Early Beginnings

Several notable early technological advancements were inevitably related to food production. In particular, as humans domesticated animals and started cultivating crops, humans gradually developed techniques to harness the strength and power of animals and other natural resources such as water and wind. Some of those techniques are still used in their original forms to date. For example, utilizing animals to pull loads, ploughing of land, husking grains, etc.; utilizing wind flow to fan and purify grains; utilizing the flow of water as a source of mechanical energy etc. Interestingly, extracting the energy contained in the flow of water and wind, continue to be among the leading energy sources which now-a-days are called "renewable energy" sources. Though the concept of harnessing these sources were around for millennia, greater efficacy happened inevitably due to control and regulate processes.

Understanding Controls

Even from the times of using animals such as cattle, horses, donkeys or elephants to realize a task, it was necessary to "control" the motion. That is to have the animal move in a certain path or speed as desired. For example, when a horse is used to pull a coach (Figure 1), the coachman would want the horse to ride along the path at a particular speed. The path and speed may be adjusted by pulling on the reins. This "control" process is accomplished through the mediation of a human "driver" who utilizes the visual and sensory "feedback" to observe if the cart is on the right track or if there is any deviation, or an "error", from the intended motion.

Therefore, this process is a classic example of "manual control" due to the direct involvement of the human "operator" or the

Figure 01 : A horse driven coach

"supervisor" in the control task. On the other hand, it is a good example of "closed loop control" due to the direct utilization of "feedback" for the control action. However, even at the early agrarian societies, the need of "automatic control" was evident. That is, the process would "correct itself", should it deviate from the intended operation, without the involvement of a human operator. Automatic control relies on some form of electrical, mechanical, hydraulic, thermodynamic or any other form of physical (i.e. without direct human intervention) feedback process. It is essential if the process is beyond human capabilities such as requiring faster response, greater strength or prolonged activity.

Historical Development of Automatic Control

In prehistory there are various tales and folklore, most shrouded in mythology, about various "automata" which were self-operating machines. There are numerous stories and legends as well as journals and accounts of such mechanisms in many early civilizations such as Greeks, Arabs, Chinese, Egyptians, Indians etc. The first evidentially known classes of practical powered motion enabled and enhanced through automatic control (at least the ones which are properly documented in the western world) were the applications in clockwork, water-wheel and wind-mill.

Clockwork, is a catch-all phrase that utilize the energy stored in taught or compressed spring mechanisms which are winding based mechanisms used in applications such as clocks. As the storage element (*viz.* the spring) loses its energy, the clock will slow down hindering the precise keeping of time, for example. Viable solutions to this problem were presented by the Dutch physicist and inventor of the pendulum clock Christiaan Huygens (1629–1695) [Figure 2], and the English physicist Robert Hooke (1635–1703) [there are no credible portraits of Hooke as Sir Isaac Newton destroyed all pectoral depictions of him] who was also the discoverer of the law of springs and elasticity. They provided viable mechanisms based on the concept of feedback to keep the clockwork running constant despite the gradual dissipation of energy from the spring winding.

Figure 02 : Portrait of Christiaan Huygens by the Dutch painter Gaspar Netscher

(Diagrams of the relevant mechanisms are not provided here due to copyright issues.)

Their contributions are worth remembering not only for the practical implications but also for their systematic analysis of the process and dynamic systems in developing the concepts and principles of "controlling dynamic systems". Therefore, these works are considered by historians of controls engineering as representing the beginnings of control theory, which is the subject encompassing the concepts and principles of "controlling dynamic systems". Inevitably, their processes were made more rigorous and generalizable due to further rigorous development of classical mechanics and calculus led by Isaac Newton (1643–1727) and others. Ultimately the influence of these "control mechanisms" paved the way to a revolution in extracting energy a few decades later.

Controlling Wind, Water and Steam Energy – Open Loop to Closed Loop Control

Harnessing the energy contained in wind and water wheels has been a common strategy to accomplish the energy needs of industry since antiquity, as in wind mills (Figure 3) and water mills (Figure 4). There are archaeological evidence of ancient water mills and wind mills in China, Egypt, Persia and many countries of Europe. These were used in almost every facet of then industry which included grinding grains,

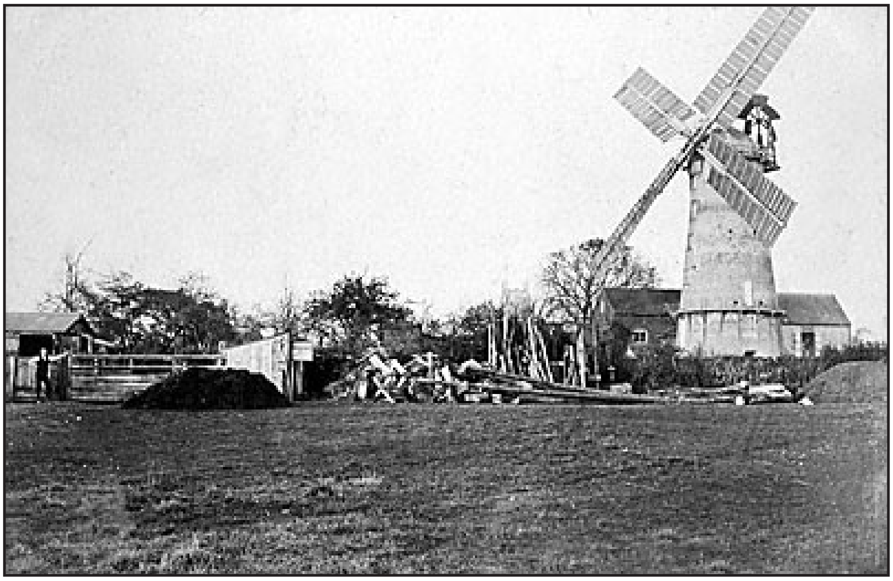


Figure 03 : View of the towermill (windmill) at Foulsham, County Norfolk, England in 1911

pumping water, irrigation and even mining operations. In 1712, Thomas Newcomen (1664–1729) invented the first versatile and commercially viable steam engine called the "atmospheric engine" adding steam energy to the energy mix. Subsequent improvements by several others culminated with the improvements made by James Watt (1736–1819) [Figure 5] who helped to drastically increase the efficiency of steam engines, making such steam engines the industry standard for energy generation. The improvements by James Watt to the steam engine were so dramatic, that some even wrongfully attribute him for the invention of the steam engine.

In either water, wind or steam models, the energy of moving substance is transferred to a useful mechanical form such as a rotary motion. In all three forms, there are fluctuations in the useful work generated due to the flow rate of the substance in motion. These common variations were somewhat mitigated using "inertial mechanisms" such as heavy rotating wheels called fly wheels or heavy rotating beams called cataracts, whose operation principle is footed on Newton's laws of motion which stipulates that a large mass will be less susceptible to sudden change of motion. These types of rudimentary controls do not rely on explicit feedback control and therefore, were simple open loop control. Their overall performance and the range of operation facilities were still limited.

Throughout the 1700s and early 1800s, water and wind continued to provide the main source of energy for many industries, especially to power mills which crushed grains which made flour out of which bread was made. Millers, especially those who used wind mills, had the nagging issue of maintaining the quality and consistency of the flour. When the wind speed increased the grinding-stones separated too much making the flour too coarse and grainy. When the wind speed was dull, the separation of grinding-stones was too little, making the flour too fine. In either extreme, the quality of the flour, and hence the quality of bread suffered. The fluctuation in the separation of grinding-stones was not something that could be adjusted by hand. So, millers were desperately in need of a mechanism to "automatically adjust" the grinding-stones so that the gap between the grinding-stones would stay constant despite the variation of the wind. In modern-day controls jargon, this would be called a "regulation problem".

Figure 04 : Water wheel and mill

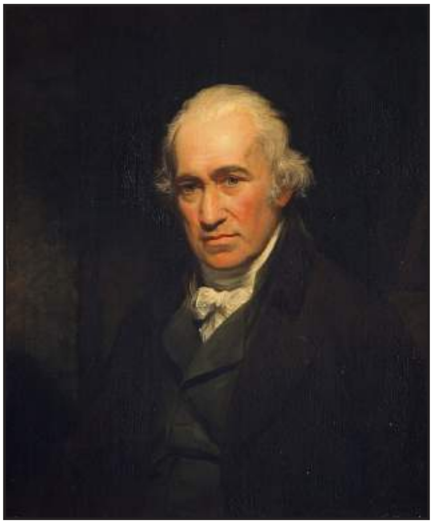


Figure 05 : Portrait of James Watt by the English painter Sir William Beechey (1806)

There were many attempts to come up with such a viable mechanism. Though somewhat similar concepts were present earlier, the first patent to such a mechanism was received in 1787 by Thomas Mead (the same person who received the patent for the gas engine). He used a cleaver trick of having two rotating masses that would rotate at a speed proportional to the wind speed. So, if the wind speed is high, those masses would rise and if the rotation speed was low, they would sag. Then, he had connected them *via* a simple lever mechanism to lift and separate the grinding-stones when the wind speed was slow and push down the grinding-stones closer when the wind speed was high so that the grinding-stone gap was consistent. This particular mechanism was anyway the first patented pre-runner to an entire class of automatic feedback control mechanisms called "governors". The name may be attributable to their role in "governing"or "controlling" the intended function (e.g. the separation of grinding-stones in wind mills) despite the variation of external energy source (e.g. wind) just like a "governor" of a city or state is expected to make sure the functions of the city or state are unperturbed by disturbances.

Mead's work inspired many more developments in the wind mill industry. In the meantime, James Watt had suffered financial losses in his innovative steam-powered mill. Later, Watt learned about the success of "governors" used in wind mills and adopted this

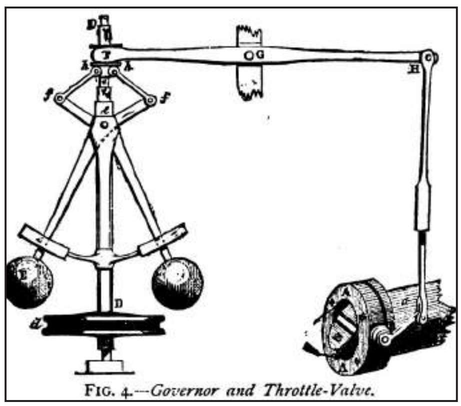


Figure 06 : Sketch of a centrifugal governor by R. Routledge in 1900

idea to steam energy driven machinery. Due to the improvements on the above type of governors these were sometimes attributed to James Watt and were known as "Watt governors", or due to their mechanism of operation as "centrifugal governors" or due to their construction using heavy balls, as "fly-ball governors" (Figure 6 and Figure 7). As these mechanical governors exert their control action based on the feedback received, they become genuine "closed loop controllers". Once governors found their way in to steam energy, they were soon developed to be much faster acting, capable of handling much larger loads and performing over a larger dynamic range. Whether it is coal, nuclear or any other fuel operated electricity generation plant, the energy source is almost always utilized to heat water and run a steam engine. Therefore, governors and other controllers played a vital role in energy generation.

When large scale hydro-electricity generation (Figure 8), and wind-electricity generation (Figure 9) picked up, as a wave of regaining popularity of renewable energy sources, those feedback control mechanisms played a crucial role in providing a reliable and consistent energy supply.

Modern Day Perspective

The control requirement of individual machines is still present in the same manner in the energy

Figure 07 : A Watt Governer on a steam engine at the Science Museum, London

Figure 08 : Victoria Dam

sector, despite utilizing new and sophisticated techniques and technologies which are in fact based on the same fundamental concepts and constructs such as centrifugal governors. However, there are new control problems, beyond what were envisioned a couple of centuries ago. These are due to the increasing renewable sources led by wind, and increasing penetration of solar photovoltaic (PV) due to continued increase in the economy of solar panels.

In the days of Mead, the fluctuation wind speed only affected the quality of flour and bread, but now it has more dire consequences in wind power generation. Fluctuation of wind induces fluctuation in the electricity generation. In solar PV generation, the electricity generation will vary due to the time of day as well as cloud motion.

Accordingly, all these sources are inter-connected and inter-mixed in a huge network called the electricity grid. There are tens of millions of consumers connected to the electricity grid. The dwindling natural energy resources and increased environmental concern has drastically raised the necessity of improving the deployment of renewable sources for electricity generation. These issues coupled with the ever-rising demand for electricity, raises major questions on the stability and control of the electricity grid.

Therefore, now we have a situation where the generation (supply) and the utilization (demand) are both varying and thereby, the control problem has not only got complicated but also diversified. The future success of human civilization, one can say, would depend on finding efficient and rapid solutions to these issues. However, rest assured, many innovative strategies are discovered and employed to tackle these problems by the best of minds all around the world, including our country.

Figure 09 : Danish wind turbines

Dr M.P.B. Ekanayake
Senior Lecturer,
Department of Electrical and Electronic Engineering,
Faculty of Engineering,
University of Peradeniya
mpb.ekanayake@ee.pdn.ac.lk

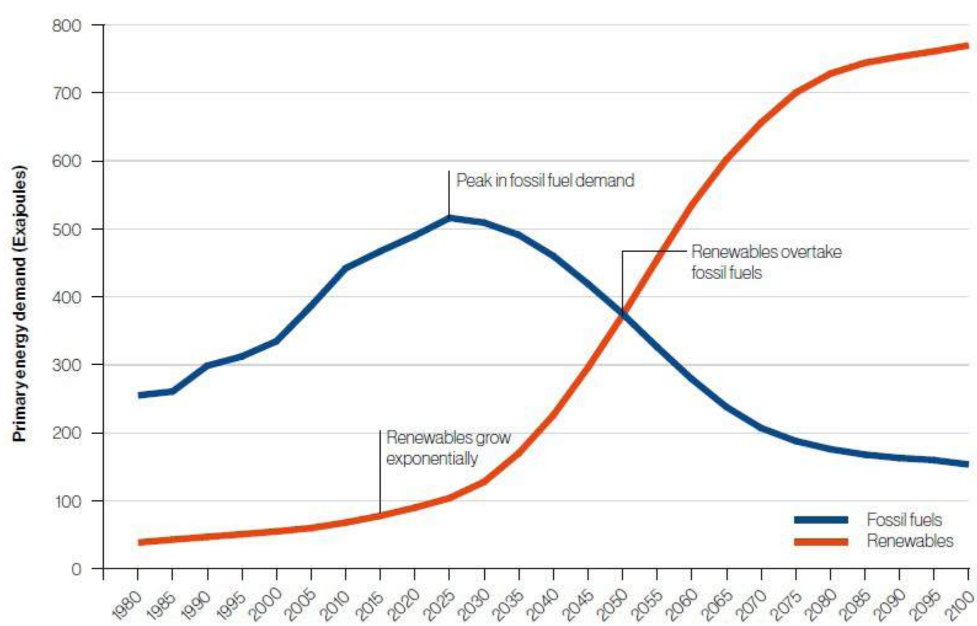
Geopolitics of Renewables: Thinking ahead towards Smart Renewable Integration

Dr G. M. R. I. Godaliyadda

Geopolitics and how it shapes the international landscape

There are many natural resources of critical importance to a nation's economy that are geographically unevenly distributed. This, while forming the underlying basis for trade and diplomacy, has also led to numerous conflicts throughout history. Further, at various stages of human history technological innovation led to the discovery of new resources or new applications for existing resources. This means that the relationships of nations with mutually beneficial economic and political interests continued to evolve through the ages as a consequence. The dynamics of these relationships shaped history in many ways. For example, the age of exploration and imperialism of the early modern age, which triggered at the backdrop of the renaissance and the industrial revolution, are a result of how nations with conflicting strategic interests reacted to the monumental shifts in the political landscape that were happening alongside technological revolutions.

Geopolitics is the study of



Note: This data is taken from the Shell Sky Scenario (2018), which has the merit of forecasting to 2100 and therefore projects the nature of the energy transformation over the course of the century. Other energy transition scenarios usually have shorter time horizons. The Sustainable Development Scenario (SDS) of the International Energy Agency (IEA), for example, only looks forward to 2040. IRENA's REmap scenario goes to 2050. Shell's forecast share of renewables and fossil fuels is similar to that of the IEA SDS scenario for 2040 as well as the DNV GL and Equinor Renewal scenarios for 2050. The IPCC 1.5 degree median scenario and IRENA REmap scenario anticipate a substantially larger share of renewables by 2050 with an earlier peak in fossil fuel demand.

Source: Shell Sky Scenario, 2018.

Figure 01 : Primary energy demand forecast to 2100

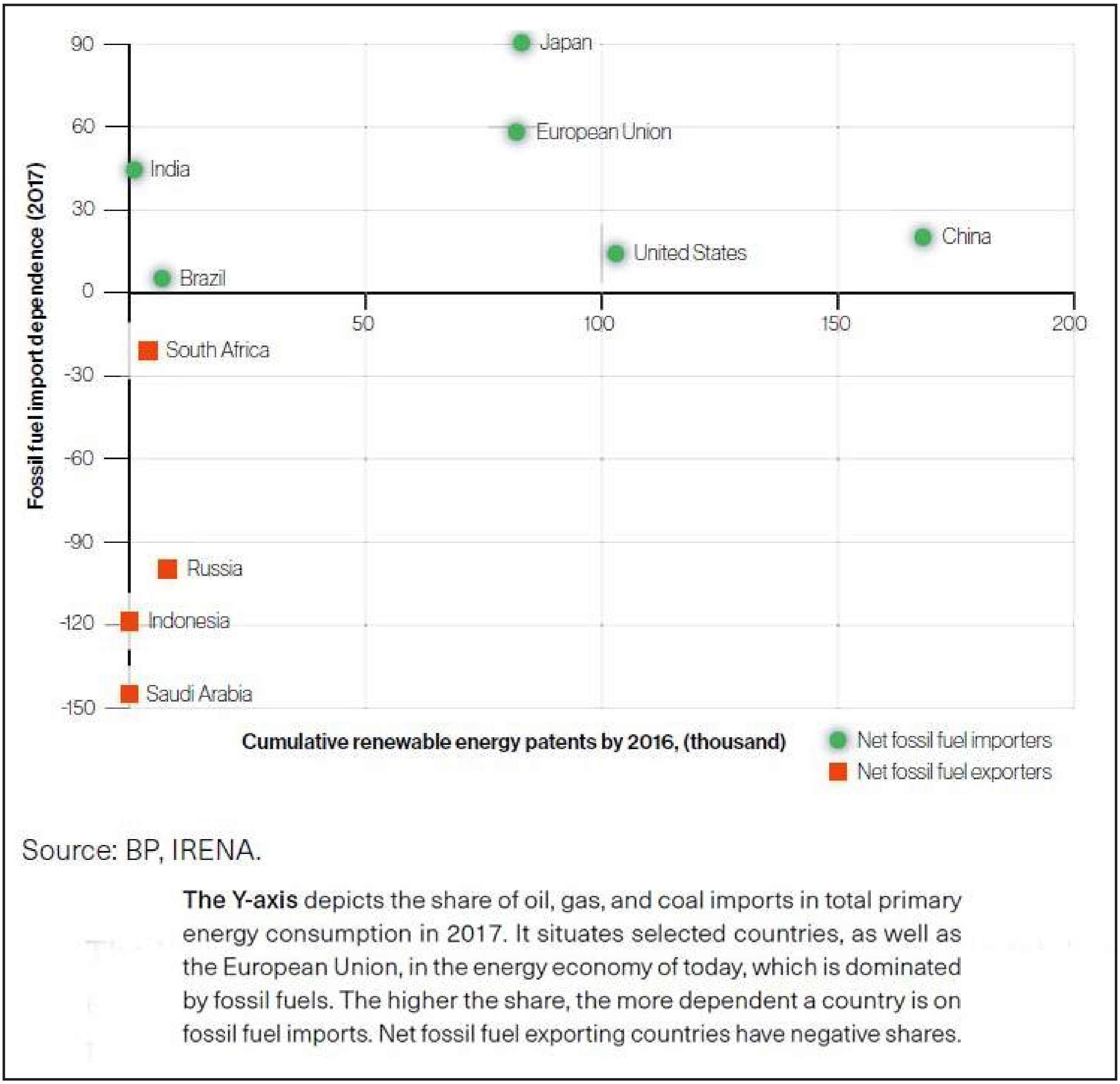


Figure 02 : Fossil fuel dependence vs renewable energy patents – Who is better prepared

'relationships of nations' based on their geography. In this context, the term 'geography' not only relates to factors such as area, natural resources, climate, and topography, but also to factors such as demography, culture, technological resources and history. These factors shape each nation's foreign policy looking outwards, while, also having a significant impact on its own internal national policy. In the recent past, due to the significant cost of war, many nations have also focused on geo-economics, a branch of geopolitics that focuses primarily on the more non-military economic aspects of international relationships based on how geographical resources are spread out in the world. Therefore, by adjusting one's national policy based on current Geopolitical and Geo-economic trends, a nation can stay ahead of the curve and reap benefits from this.

To explore this further, let us take a simple hypothetical example of how geopolitics can affect two countries looking to improve their economic output by use of free trade. Let us assume Britain and Brazil over produce Textile and Coffee, respectively. The surplus would be made available for export

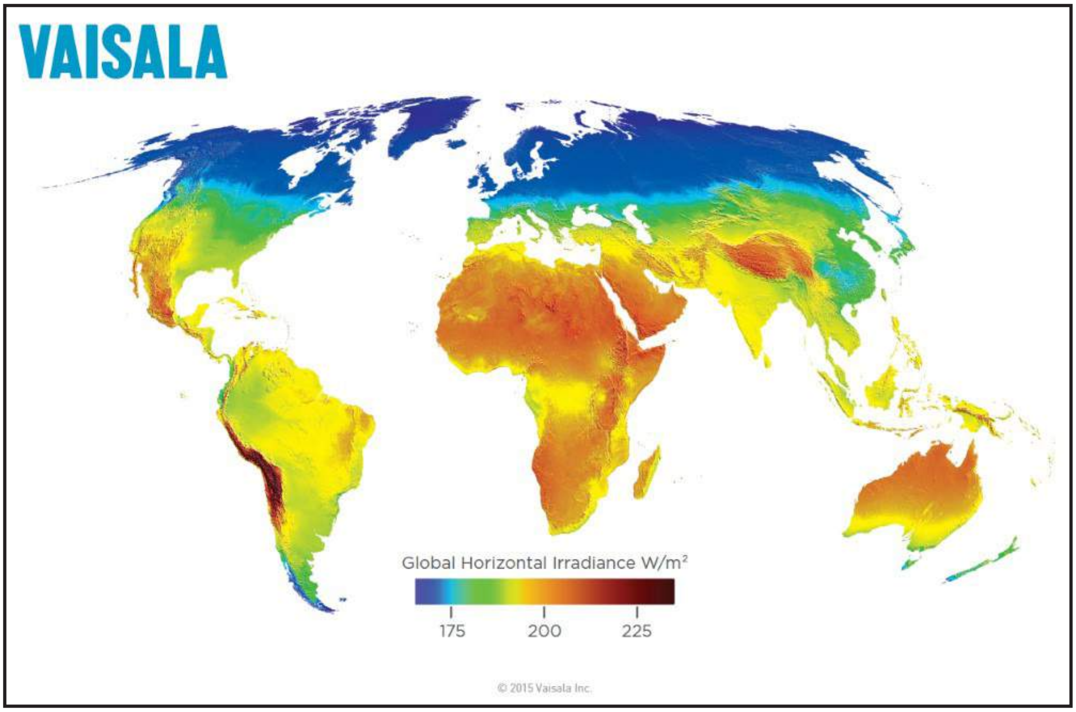


Figure 03 : Global solar resource potential map

trade between the two countries. Hence, both countries will have access to both products at a lower price compared to what it would have cost each country to produce sufficient quantities of both products in-house. This is because of the per capita resource gain of each country that results from its specialization in manufacturing one product, as explained by the Ricardian model (named after 19th century British political economist) in economics. Hence, in this oversimplified scenario it would seem both countries would benefit from free trade. However, one should also consider the long-term effects of this arrangement. As time passes, Britain would get richer in this model compared to Brazil as Textile is what is called a "Gateway industry" that leads to industrialization, automation, mechanization, urbanization and also many other derivatives or related industries such as chemicals, machine tools. As a result, it stimulates industrial growth in Britain, enabling it to yield higher profits in the long term. Furthermore, Britain can invest these profits in more innovative production techniques in Britain itself and elsewhere, for example, in Brazil.

The above example relates to the Geopolitical situation of the 18th and 19th centuries that led to the rapid industrialization of many western countries. This in turn created a massive shift in the Geopolitical forces of the time, leading to vast differences in the quality of life and economic situations of countries all over the world. However, such shifts happen in waves and have continued to occur throughout the 20th century leading up to this very day. Geopolitical landscape shifts have occurred even more frequently as we approached the later part of the 20th century due to the exponential growth of engineering and technology. Hence, identifying and responding to key factors that can significantly impact geopolitical machinations, increases the versatility of nations under such volatility.

Geopolitical Trends of Energy with the advent of Renewables

The impact of Energy on the geopolitical landscape significantly increased post-industrial revolution. For almost the entirety of the 20th century the Geopolitical landscape of the world in terms of energy was defined by fossil fuels, namely, oil and gas. Many of the wars waged in the recent past as well as on-going conflicts and alliances were shaped largely through the Geopolitics of oil and gas. This is due to the fact that a significant portion (more than half) of energy used for industrial and transport sectors are from fossil fuel sources. The high oil prices of the 1970s and the more recent lowering of oil prices were the obvious result of geopolitical maneuvering.

However, most recent projections show that renewable energy would become the leading source of primary energy consumption by 2050 (Figure 1). This is in part due to the 2015 Paris agreement which called for dramatic changes to the global energy mix by encouraging its signatories to incentivize the growth and development of low-or zero- carbon energy producing technologies. Renewables have made significant inroads into the energy mix of many countries including the major energy consumers such as India, China, USA and Western Europe. This is due to the policy incentives and growth in China, energy emission policies in Western Europe, and declining renewable costs and policy in India. Hence, the place of renewables in the Geopolitical landscape is set, what remains is to predict how they reshape it.

There are several mechanisms that can affect the way renewables might shape the Geopolitical landscape. As was the case with the fossil fuel industry, 'critical raw material' has a high geopolitical strategic value while requiring low capital. The rare earth minerals, such as Neodymium used for magnets in wind turbine generators and motors of electric vehicles, Lithium and Cobalt used for energy storage, and others such as Indium that is used for solar cells, have the potential to create cartels around them, as was the case for the oil and gas industry.
The need for continuous growth in the renewable energy sector has resulted in numerous technological innovations, and increased investment in research and development (R&D) in the area. Countries rich in capital such as China, US, EU and Japan have invested heavily in clean energy technological innovations, with the goal of staying ahead of the curve in the midst of shifting geopolitical dynamics. This has led to a rapid increase in renewable energy related patents in those countries (Figure 2). Higher efficiencies in solar photovoltaic (PV) modules, taller wind turbines, are examples of such innovations that have led to increased productivity in this sector.

As the need for efficiency increase paved the way for initial innovation, the investment in R&D spurs on more innovation in new frontiers relating to renewables. The early research focused mainly on supply-side efficiency growth as mentioned above. Lately the focus has shifted to adapting consumption-side behaviour towards clean energy.

Electrification of 'hard to electrify' sectors such as transport and heavy industry is one such new frontier of research that focuses on consumption-side adaptation. The integration of renewables to the grid has resulted in the need for smart and versatile mechanisms for integration of generation and distribution in energy systems. This in turn has led to the exploration of applying new technologies such as smart grids, the internet of things (IoT), Artificial Intelligence (AI), and Big Data to the energy industry. Further, the electrification of transport systems as well as the volatility in renewable energy supply has generated interest in energy storage systems.

How can Sri Lanka look ahead?

Countries that make use of geopolitical strategy and foresight to react to shifts in the geopolitical landscape, as history has taught us, are in a better position to reap the rewards of the incoming change. Already, major powers are investing heavily in R&D for the

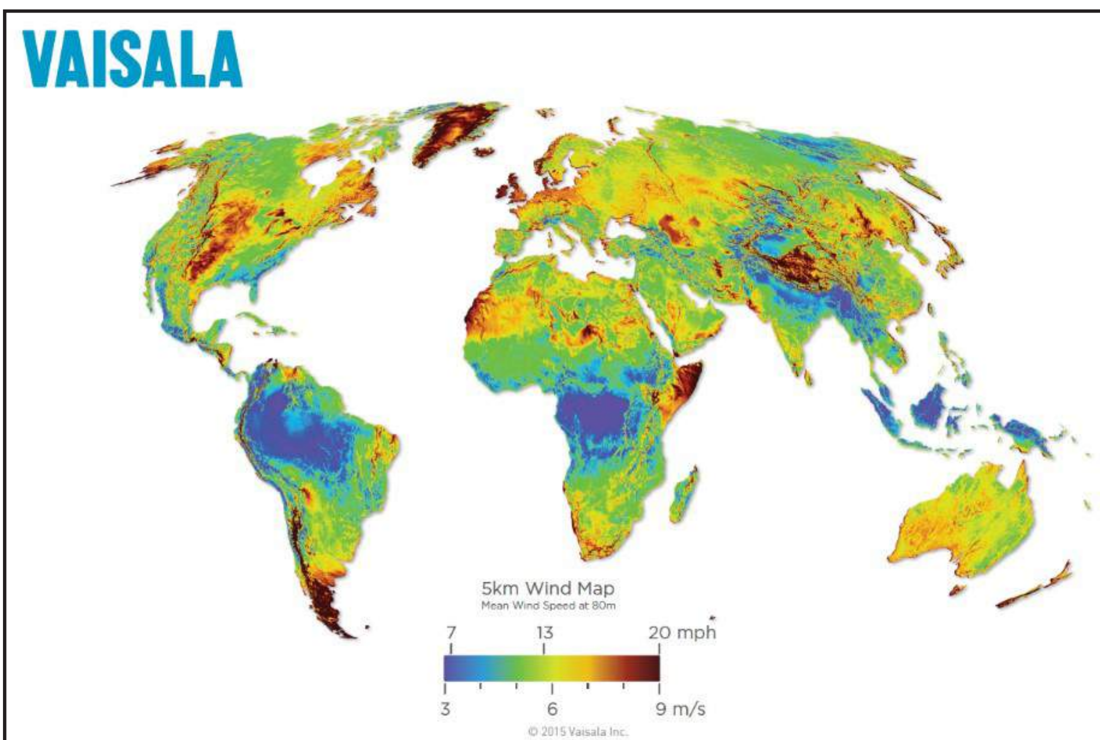


Figure 04 : Global wind resource map

energy sector, which has resulted in them obtaining a large number of patents in this field. This not only gives them access to profit through intellectual property, with the rapid growth of the renewable energy sector, but also gives them significant leverage in the geopolitics of energy.

However, the fact that energy politics are shifting, presents new opportunities for a nation such as Sri Lanka as well. The geopolitics of renewable energy are clearly tied to technological innovation as discussed earlier. New frontiers of research yet untapped or at an infant stage continue to open up in areas such as IoT, AI, Big Data and the Smart Grid and can lead to innovation even with the limited capital that we possess. Mainly because R&D creates a positive feedback loop of investment and growth leading to a cycle of growth if tapped into at the correct time. Furthermore, the geographical placement of Sri Lanka puts it at an advantage in terms of solar and wind resource availability (Figures 3 and 4). This is in addition to the hydro-electrical resources the country already possesses. A clear national initiative towards R&D in the energy sector can stimulate the country towards a positive growth cycle even with the relatively low capital we possess.

There is a clear argument for focusing the initial phase of R&D activities on fields such as smart grids, and application of new technologies such as AI, IoT and Big Data as a support system to its implementation. Current status of R&D activities in Sri Lanka include, development of software and hardware-based technologies for the Smart Grid, production of graphene and activated carbon for energy storage devices, to name a few. These will not require the 'rare critical raw material' that would otherwise hinder progress or leave us at the mercy of a supplier. In addition, steering the national energy mix towards renewables would also remove dependencies over fossil fuel producers. This would hopefully trigger the positive feedback loop of innovation and investment.

What is interesting about technology driven geopolitical waves is that they have always given the opportunity to countries not rich in natural resources to become players in the geopolitical stage. They also lead to the growth of new derivative industries that create new employment opportunities for the populace. For example, an energy grid enriched by AI or IoT would create employment in communications, electronics and computing. This would modernize the education sector leading to further sustainable growth.

A proactive approach towards this is paramount because once the renewable energy sector grows beyond a certain point the geopolitics would have already shifted. Thus, resulting in cartel like behaviours from the new suppliers, making investment in renewables even more expensive. This in turn leads to complete dependency on those geopolitical players. On the flipside, innovation leads to partnerships between nations opening up more opportunities for growth and knowledge sharing.

The most significant difference between renewable energy and fossil fuels is its availability in one form or the other in most countries, resulting in less energy choke points. In addition, renewables are inexhaustible energy flows as opposed to fossil fuels, which are storable stocks that are more susceptible to price maneuvering. Finally, they are more decentralized in generation making monopolization difficult.
It is blatantly obvious that the power balance of geopolitics can therefore shift with the growth of renewable energy.

Countries that respond well to this shift with investment towards technological innovation in related fields and modify national policy to accommodate clean energy initiatives are highly probable to have a better placement in the race.

Dr G. M. R. I. Godaliyadda
Senior Lecturer,
Department of Electrical and Electronic Engineering,
Faculty of Engineering,
University of Peradeniya
roshangodd@ee.pdn.ac.lk

DC Returns with Renewables

Prof. J.B. Ekanayake

Early Installations

Alternating current (ac) is well known to everyone as our homes, commercial entities and factories are supplied by ac. However, early installations were direct current (dc). World's first dc generation station was opened on 4 September 1882 at 257 Pearl Street, New York. This was as a result of the pioneering work of Thomas Alva Edition (Figure 1). Edison's power station began supplying electricity to customers in the First District, covering 0.65 square km area.

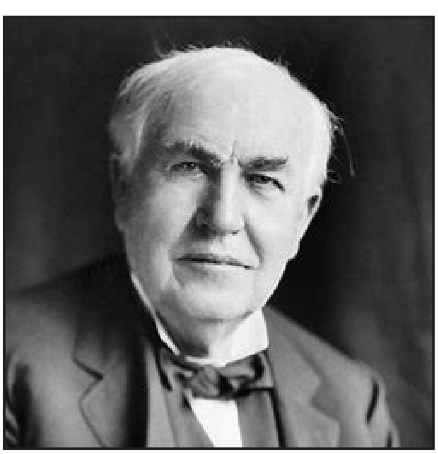
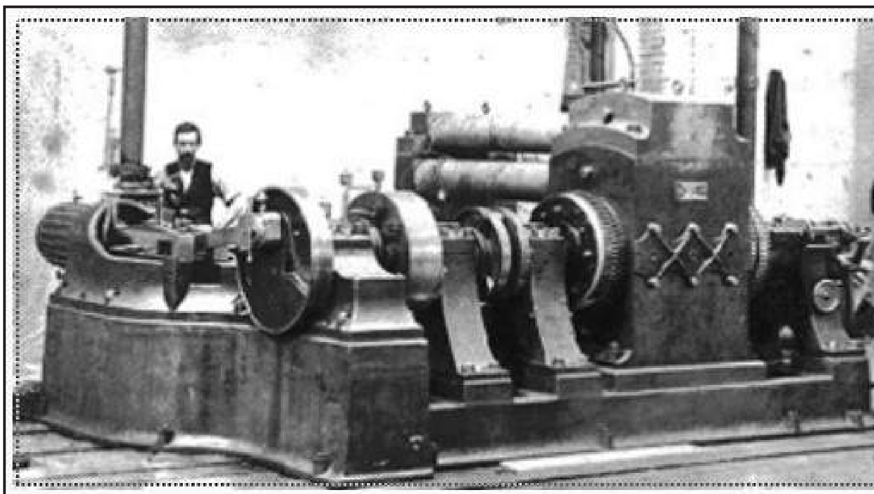


Figure 01 : Thomas Alva Edison (11 Feb 1847 - 18 Oct 1931)

To supply electric power to the lights within Pearl Street's service area, Edison and his team developed the 27-ton "Jumbo" constant-voltage dynamo (Figure 2). There were six dynamos installed at Pearl Street, and each had a capacity of about 100 kW. The dynamos were driven by reciprocating steam engines supplied by four coal-fired boilers.

Edition's project involved the installation of about 24.4 km of underground cables. The original system operated at 110 V dc and used a two-wire configuration. Because of the large amount of costly copper required, Edison quickly changed the cabling into a 220 V, a three-wire design that significantly reduced the amount of copper needed.

Followed by the Pearl Street station, hundreds of improved versions of the Pearl Street design were installed. However, a low-voltage dc system has inherent disadvantages, and the main one was high line losses that limit the distance that the dc electric power can be



Edison's Jumbo dynamo. Courtesy: National Park Service, Edison National Historic Site.

Figure 02 : Edison's Jumbo dynamo

economically transmitted.
By the mid-1880s, ac systems began to compete with Edison's dc system. The invention of the ac transformer by Nikola Tesla permitted the economic and efficient long-distance transmission of electric power at high voltages, thereby resolving the major disadvantage of low-voltage dc systems. Therefore, by the end of the 19th Century, dc systems began a gradual and inevitable decline.

HVDC Transmission

In the 20th Century, all low voltage electrical distributions were ac. Even though most of the high voltage (HV) circuits were also ac, with the invention of the mercury arc valve in 1902 by Peter Cooper Hewitt, there was an interest in dc transmission mainly to connect asynchronous systems. The mercury arc valve is an efficient ac to dc rectifier, and is shown in Figure 3. For example, in 1932, General Electric tested mercury-vapour valves, and constructed a 12 kV dc transmission line to convert 40 Hz generation to serve 60 Hz loads at Mechanicville, New York.

The Moscow–Kashira system originally built in Germany and installed in Russia in 1951, and the first commercial HVDC line between the mainland of Sweden and the island of Gotland built-in 1954, marked the beginning of the modern era of HVDC transmission. Mercury arc valves were common in systems designed up to 1972. The Nelson River Bipole 1 system in Manitoba, Canada is recognised as the last

Figure 03 : Probably the last operating mercury arc rectifier in the world; this is still serving students at the Department of Electrical and Electronic Engineering, University of Peradeniya

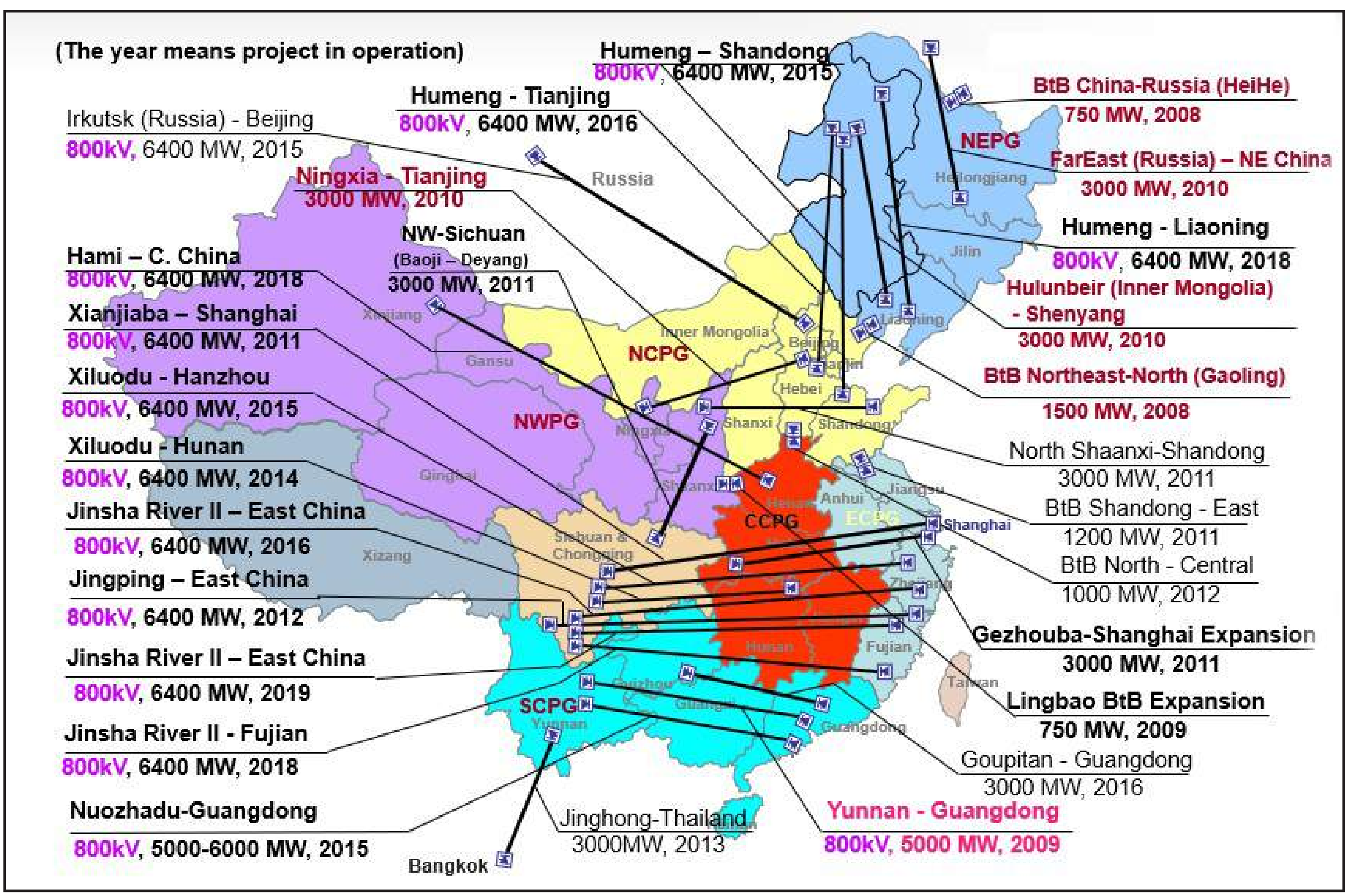


Figure 04 : HVDC connections in China

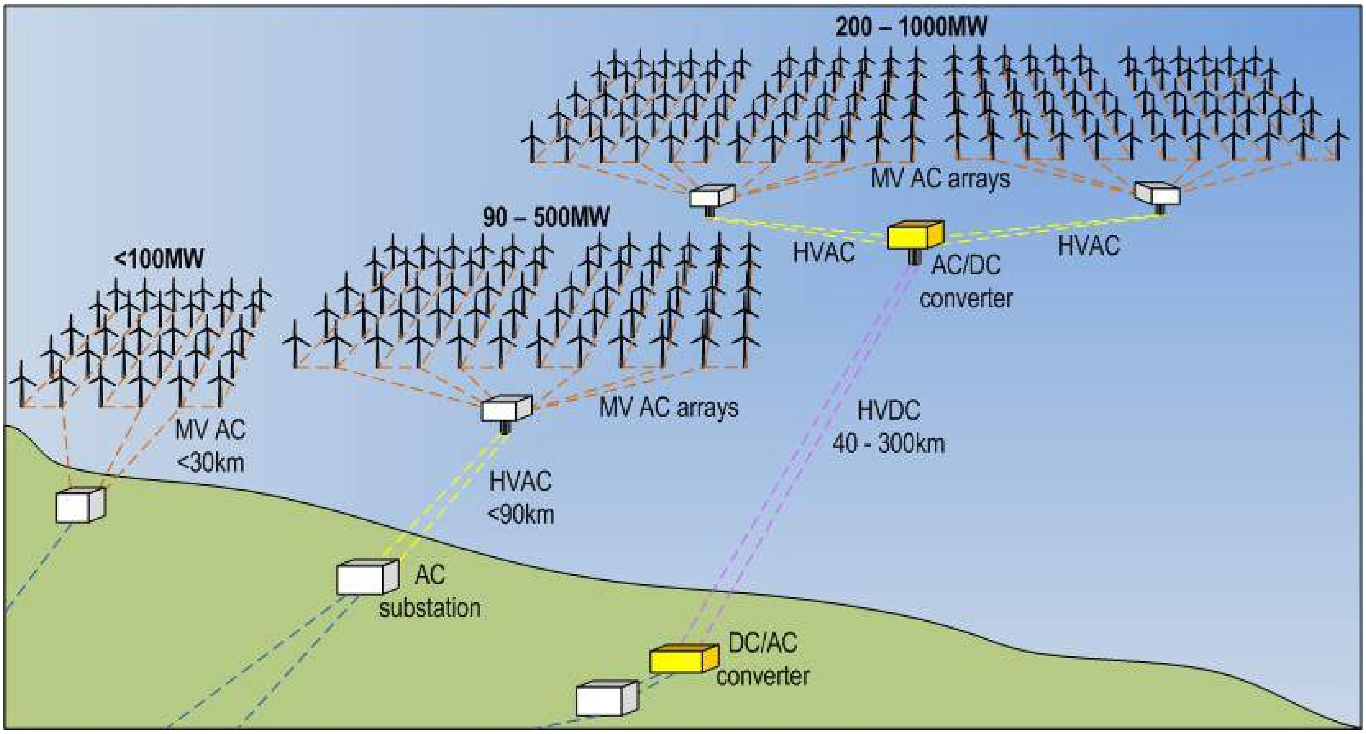


Figure 05 : Offshore wind farm connections

mercury arc HVDC system.

After the development of the silicon controlled rectifier (SCR) or thyristor in 1956 by power engineers at General Electric, all mercury arc HVDC systems have been either shut down or converted to use solid-state devices. The first complete HVDC scheme based on thyristor was the Eel River scheme in Canada, which was built by General Electric and went into service in 1972. Today, there are a large number of thyristor-based HVDC schemes operating in the world, while China being the pioneers. Figure 4 shows the HVDC schemes operating or planned in China as of 2020. Changji-Guquan, the world's first ±1,100 kV ultra-HVDC link, set a new world record in terms of voltage level, transmission capacity and distance. It is capable of transporting 12,000 megawatts over 3,000 km.

More HVDC schemes were developed due to some inherent advantages of dc schemes compared to their ac counterparts. There is a limit to the distance that bulk ac can be transmitted unless some form of reactive compensation is employed.

For long overhead lines, either alternating current with reactive compensation or direct current may be used. If undersea crossings greater than around 50 km are required, then, because of the capacitive charging current of ac cables, dc is the only alternative.

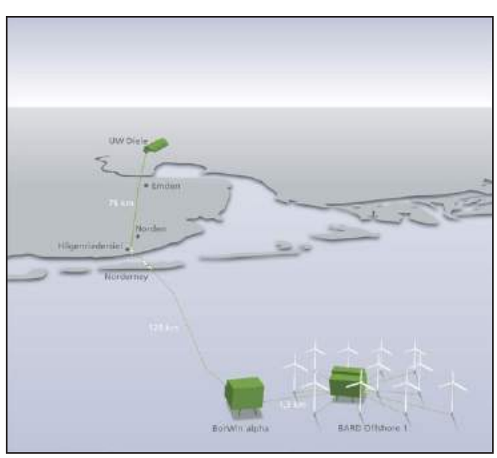


Figure 06 : BARD Offshore 1 connection

Further, HVDC allows the interconnection of two large ac systems without having to ensure synchronism (e.g. the U.K.-France cross-channel link of 2000 MW) and the interconnection between networks of different frequency (e.g. the connections between north and south islands in Japan, which use 50 Hz and 60 Hz systems).

Since about 2000, an alternative technology using voltage source converters (VSC), has become available although at lower power levels than thyristor-based HVDC. The valves of VSC HVDC use semiconductor devices such as Insulated Gate Bipolar Transistor (IGBT) that can be turned on and off (compared to thyristors that can only turn on and commutated using some extra circuitry). This ability to turn the valves on and off allows the converters to synthesise a voltage wave of any frequency, phase and magnitude, within the rating of the equipment.

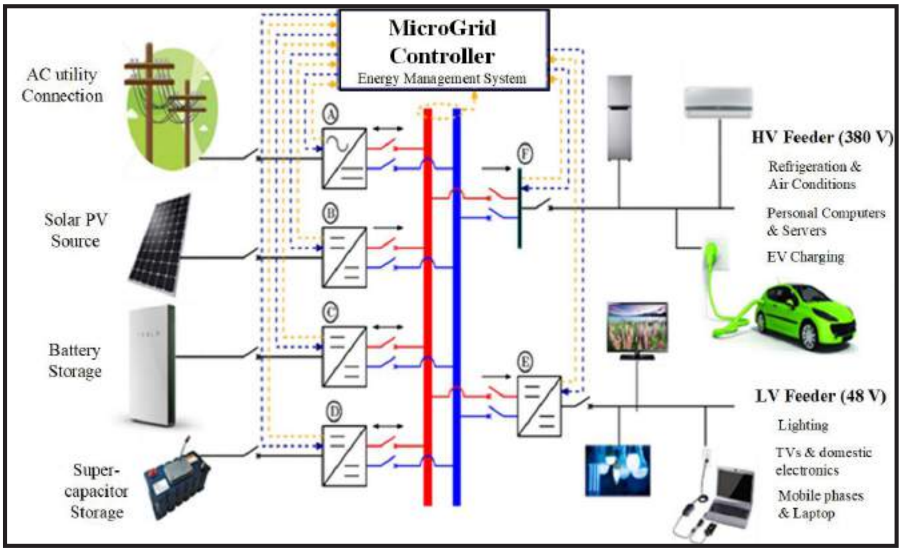


Figure 07 : Hub of a Dc Microgrid Developed by the Department of Electrical and Electronic Engineering, University of Peradeniya

DC for Renewable Connections

Today there is a growing interest for offshore wind farms. For large offshore sites that are far away from the main grid and generate 100s of MW of power, HVDC has become a preferred choice. Figure 5 shows the possible connection considerations for offshore wind farms. For offshore wind farms having generated power and distance of 200 MW, 300 km to 1000 MW, 40 km, HVDC is the preferred choice.

The German grid operator TenneT has already connected a number of offshore wind farms using HVDC technology. BARD Offshore 1 is the first offshore wind farm to be connected by HVDC. It employed more than 100 km of submarine cables. This connection is shown in Figure 6. With an output of 800 megawatts (MW), BorWin2 is the first large-scale offshore connection that TenneT has implemented. Since January 2015, two offshore wind farms Global Tech I having a capacity of 400 MW and Veja Mate having a capacity of 400 MW have been feeding wind energy into the German power grid via BorWin2. It employsVoltage-Sourced Converter based HVDC, and the total cable length is 200 km, out of which 125 km are submarine cables.

DC in Medium and Low Voltage Networks

Currently, power produced by a photovoltaic (PV) system undergoes a dc to dc and dc to ac transformation before consumed by the loads. At the load end also a conversion from ac to dc takes place as many loads such as LED lights, entertainment equipment and computer equipment are internally operated with dc. To reduce losses associated with power conversion stages, thus increasing the efficiency of PV utilisation and conserving the energy utilisation, dc MicroGrid becoming an attractive solution (Figure 7).

One of the bottlenecks for the uptake of renewable energy sources is their intermittency and variability. Therefore, unless supported by the main grid or integrated with energy storage, they cannot reliably supply the loads. Energy storage such as batteries, flywheels, and fuel cells either are inherently dc or have an internal dc bus that can be easily integrated to a dc grid. Therefore, with the realisation of the dc MicroGrid, dc will soon conquer the whole spectrum of the power industry.

Prof. J.B. Ekanayake
Chair Professor
Department of Electrical and Electronic Engineering,
Faculty of Engineering,
University of Peradeniya
jbe@ee.pdn.ac.lk

Green Communications for a Low-Carbon World

Dr S.A.H.A. Suraweera

Since the development of wireless technology in the last century, mobile radio services have penetrated into all sectors of the society. Today, a variety of wireless systems are in use and there has been an increasing demand for high throughput data services in indoor environments as well as outdoor environments. Moreover, encouraged by the popularity of smartphones, ebook readers, Internet-of-Things (IoT) and the widespread use of social networking applications, upcoming 5G wireless systems are expected to connect billions of users and hundreds of thousands of devices across the world. However, operation of these wireless systems comes at the price of high energy consumption. As a result, today's Information and Communication Technology (ICT) has put a heavy strain on the planet's rapidly dwindling energy resources. Therefore, to reduce the carbon foot print of wireless operation, there is a need to develop energy-efficient green techniques.

On a parallel development, smart grids marketed as the next generation of power delivery network aims to automate and control energy distribution in different parts of the electric grid. By doing so, smart grid operations can reduce energy losses and promote efficient energy usage among the end-users. To this end, telecommunication services provide an efficient mechanism to enable smart grid operation and optimization.

In the next sections of the article, our aim is to introduce energy-efficient green communication techniques as related to modern wireless system implementation as well as to explain the usefulness of ICT for implementing the smart grid.

Solutions that can Meet Throughput Requirements in Mobile Communication Systems

Today's data-hungry applications require high throughput communications. To provide such requirements, cellular system

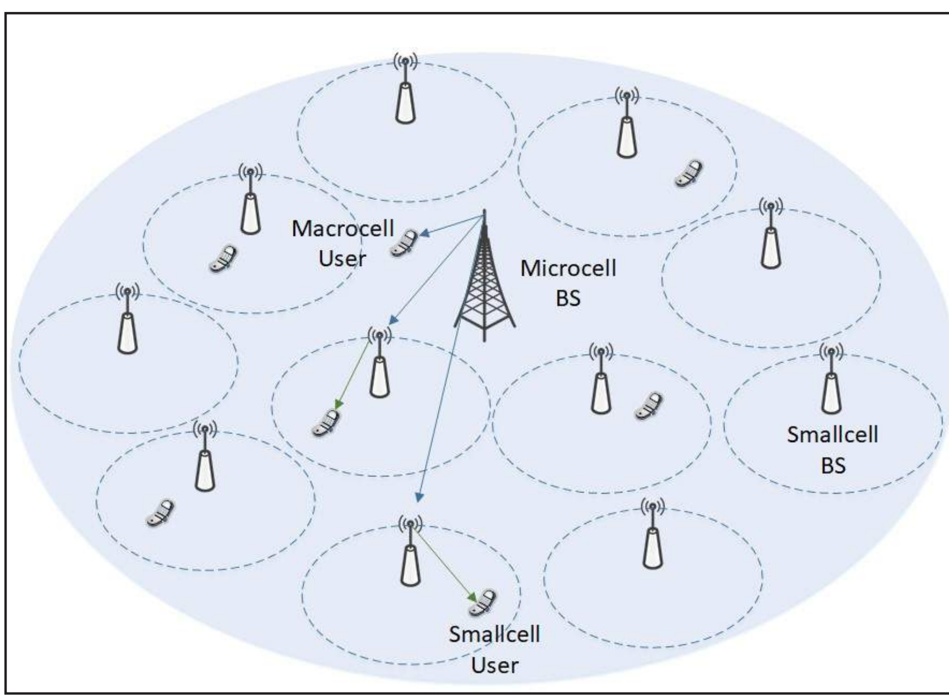


Figure 01 : A small cell network with reduced transmitter-receiver distance

designers have considered several solutions such as [1]

•Reduction of transmitter-receiver distance so that signal attenuation becomes low

•Exploitation of unused large swaths of new frequencies primarily in the millimeter wave bands and

•Deployment of massive multiple-input multiple-output (MM-MIMO) antenna array terminals.

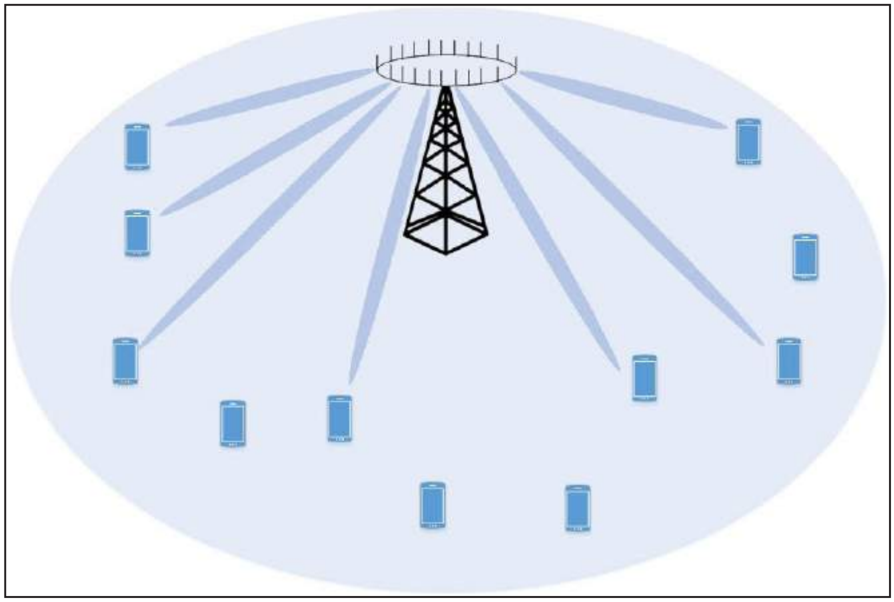


Figure 02 : A massive MIMO network with hundreds of antennas at the base station

In principle, reducing the transmitter-receiver distances (Figure 1) allows the transmit power to be reduced to support a given quality-of-service. However, such networks should be carefully planned so that interference does not become a major source of performance degradation. Millimeter waves do not travel long distances and thus only creates limited interference. Still power hungry transceiver chains are required to implement millimeter wave networks. Further, due to the use of a large number of antennas, high circuit power consumption in MM-MIMO systems (Figure 2) can result in low energy-efficiency. Hence, it is clear that while these solutions can increase the system throughput, network energy consumption should be minimized and made sustainable. Some of the green technologies that can improve the energy efficiency of modern communication systems are described as follows:

Green Solutions for High Energy-Efficiency

a) Energy-Aware Cell Design

With the introduction of every generation of cellular systems, we have witnessed shrunken cell sizes. Due to the small cell sizes, users often cross several cells over the period of their service. As a result, handover requirements in the network become common and thus increase the signaling demand and energy consumption.
To take care of handovers, umbrella cells are deployed. Specifically, a large macro-cell having an extended coverage

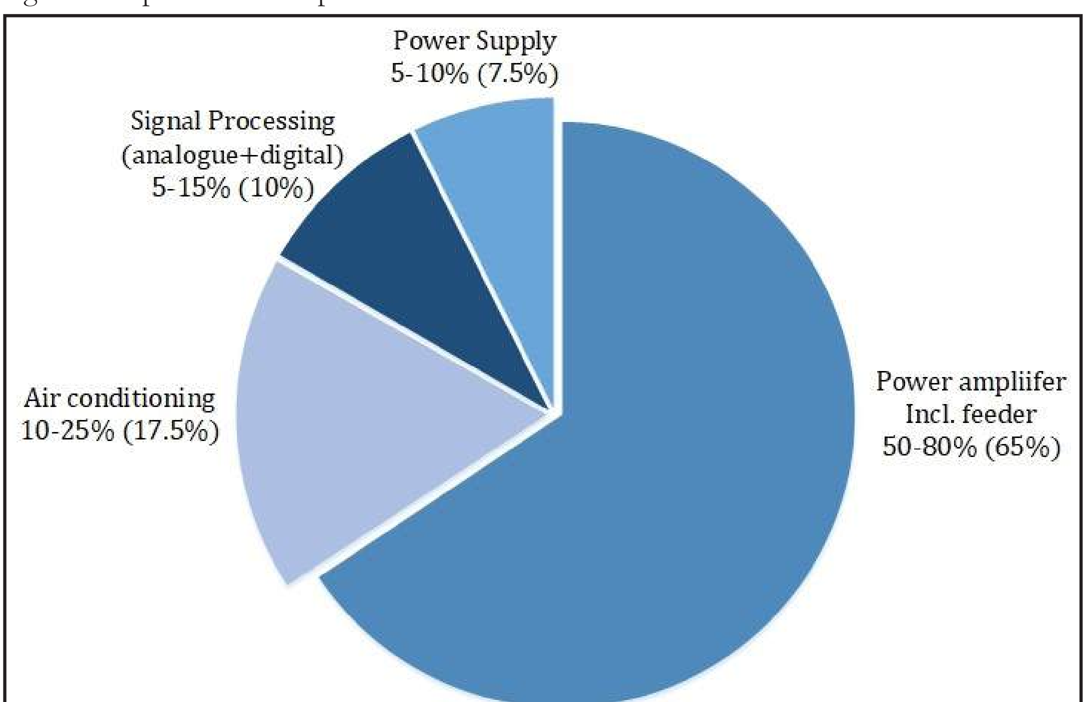


Figure 03 : Power consumption in base stations [2]

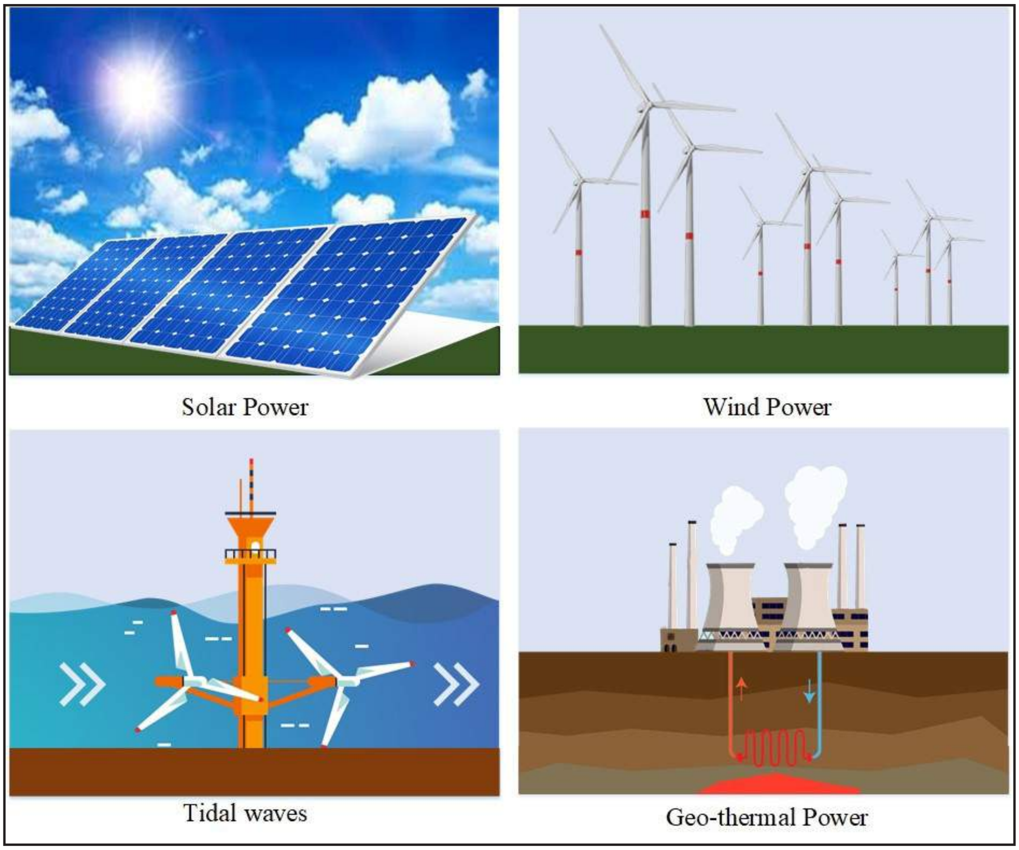


Figure 04 : Renewable energy sources

area and extra radio resources together with micro-cells, which operate on millimeter wave small base stations to reduce signaling overhead are deployed.

b) Base Station on/off Switching

Statistics show that operational load on most of today's base stations are not heavy [2]. However, they are kept switched on regularly and hence, rather unnecessarily consume large amounts of energy. In addition, day traffic shows dips at certain times of the day, for example at night and early morning hours. Therefore, switching off transmitters at optimized time intervals is an effective policy to promote energy savings.

c) Power Control and Mode Selection

Utilized since the inception of wireless days, power control is an effective mechanism to prevent interference among receivers. Without power control, interference can severely degrade both the uplink and downlink performance of wireless networks. In the literature, depending on the availability of channel state information, various optimal and sub-optimal power control schemes that minimize transmit power while guaranteeing performance above pre-defined values have been proposed. Mode selection is another energy saving strategy that can be implemented in cooperative/machine-type networks. In machine-type communication, devices have the choice of communicating through a regular base station (cellular mode) or directly with each other and enable energy-efficient design.

d)Green Transreceiver Architectures

Conventional microwave and millimeter wave systems use all-digital architecture that need a reserved radio-frequency chain at each antenna [1].

However, power consumption in such all-digital architecture is excessive due to the need for very high speed sampling. To lower the power consumption, designers can deploy an analog beamforming architecture where rudimentary analog phase shifters are used instead. However, analog beamforming has the drawback of only supporting single user transmission. As such, a compromise between digital and analog beamforming, namely, a hybrid beamforming approach to improve the energy efficiency becomes an attractive solution.

e) Power Amplifier Improvements

As one of the essential parts of a base station, radio consumes more than 80% of base station's energy requirement [2]. Further, half of the power of radio is consumed in the power amplifier (Figure 3). Most of the power is wasted as heat in the power amplifier due to low efficiency design. Surprisingly, total efficiency of currently deployed power amplifiers in systems such as GSM, UMTS and CDMA only range from 5% to 20%. Therefore, there is much scope to improve the efficiency of power amplifiers through innovative electronic design. Moreover, reducing the high peak-to-average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) signals will allow power amplifiers to operate at a high efficient point and thus to save energy.

To this end, use of renewable energy sources such as solar, wind, geo-thermal and tidal waves (Figure 4) are alternative solutions that can reduce operation costs and greenhouse gas emissions.
Recent advances made in the areas of solar panel technology, wind turbine technology and electronics continues to fuel significant interest on renewables as alternative sources of energy for telecommunication systems. Energy harvesting from renewables for system operation comes at the price of several challenges. In general, harvested energy from sources such as solar and wind power are intermittent, subjected to climatic conditions and may not be sufficient to operate large networks for prolong periods. Moreover, solar energy is not available at night time and also cloud cover significantly affects its generation. Wind power is available only at certain locations and transportation to the required telecommunication sites can result in heavy energy losses.

A fundamental characteristic of energy harvesting communication systems is that energy cannot be used prior to harvesting. Hence, they should be equipped with a battery of sufficient capacity for storage. Also, there is a need to optimize system operation depending on the statistics of energy arrivals. In particular, resource allocation algorithms that work either on offline or online policies should be invented to match communication performance requirements with available energy in the devices. Another pragmatic approach that can be adopted to overcome the intermittent nature of renewable sources is to harvest energy from a variety of sources. In this way, they could be used in a complementary manner to provide uninterrupted power to the communication devices. In emerging architectures such as distributed antenna systems, location diversity can also be exploited to implement an efficient network based on renewable energy sources. For example, transmitters located in favourable locations can

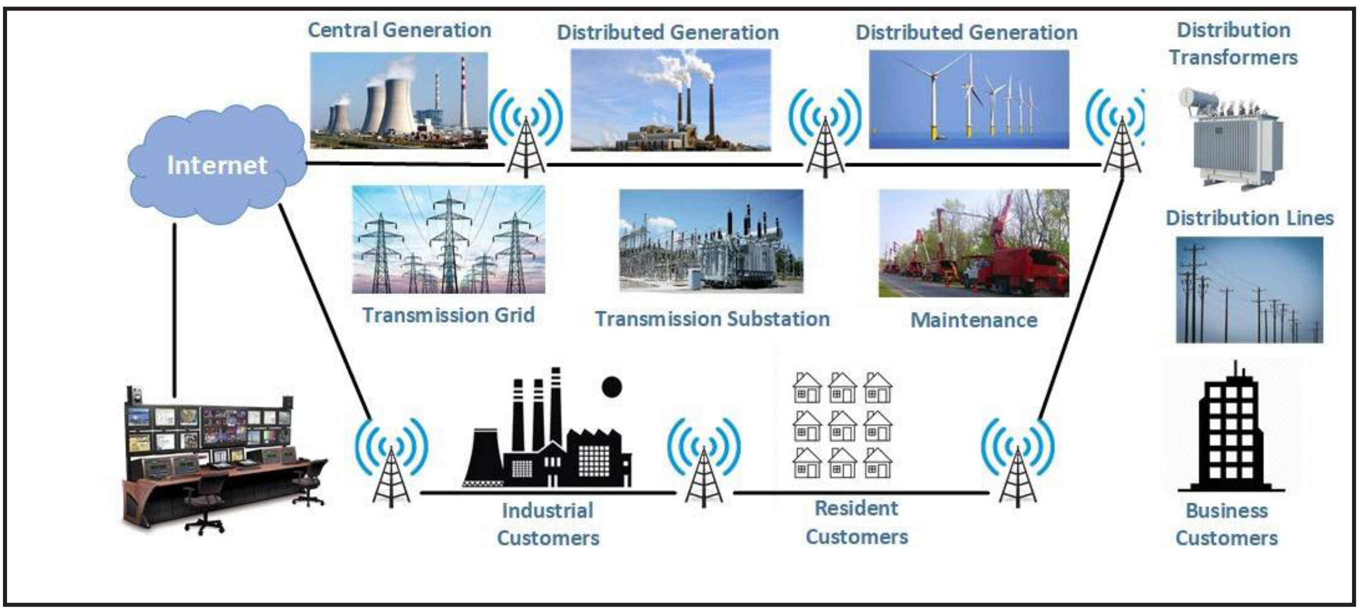


Figure 05 : Communications in the Smart Grid

Renewable Energy Resources for Sustainable Communications

There are many remote parts in the world where telecommunication system operators do not have sufficient access to grid electricity. A popular solution in such situations is to use diesel powered generators that release large quantities of CO_2 into the atmosphere. Also, diesel has to be transported to the cellular site and as a result, telecommunication operators have to tolerate extra costs with network operation.

harvest more energy. Such base stations can assist the network by serving additional users or by transporting energy to other transmitters in need of energy. In this final part of the article, role and key aspects of communications in smart grid deployments that open up new ways of improving the energy efficiency of the present electric grid is described.

Communications for the Smart Grid

Smart grid technology promises to improve present day power grids with real-time control and energy efficient operations. As an example, within the smart grid architecture, household consumers can decide to store excess energy they generate and next support peak demand times of the network as required. Moreover, inclusion of renewable sources and storage devices in the electric grid allows the possibility of efficient demand to supply matching.It is worthwhile to note that data exchange in the grid creates new security problems and privacy issues that should be addressed.

It becomes clear that integration with communication systems opens the way to deploy flexible, scalable and secure smart grid solutions (Figure 5). Communication systems allow

•real-time load monitoring
•automated demand-response
•grid parameter visualization and
•asset tracking

tasks within the smart grid. Further, wireless-assisted smart metering enables measuring consumed power of devices; hence, the possibility of real-time pricing becomes feasible. Communication systems are essential to the integration of renewable energy sources into the electric grid. They allow collection and transfer of relevant data within the smart grid so that resource allocation algorithms can be performed at the network operations center.

There are several communication requirements such as
•bandwidth
•reliability
•latency and
•security

to support different smart grid functions. Devices attached to the smart grid should have suitable bandwidths assigned to allow real-time two-way communication for data transfer. Communication reliability is another important factor to ponder, since smart grid environments are harsh, experience high temperatures and subjected to strong electromagnetic interference. Some smart grid applications may have stringent delay requirements. Therefore, in general, low latency communications are preferred. Finally, security is important to thwart intruders from hacking into the smart grid to trigger a system collapse. As a result, secure communication protocols supported by strong data encryption procedures should be used.

There are several communication technologies that can support smart grid applications. Among them, 4G LTE cellular systems allow long distance communication through backbone and internet connections. Technologies such as WiFi are suitable for advanced metering applications that records energy readings. In order to connect power meters in a wide area, low-power wide-area network (LPWAN) technologies such as narrowband Internet-of-Things (NB-IoT) and Long Range (LoRa) can be used. Further, home appliances can be monitored using wireless sensor networks such as ZigBee and Bluetooth low energy. Powerline communications and Ethernet that support a range of data rates are also popular wired technologies useful for smart grid communications.

References

1) Q. Wu, G. Y. Li, W. Chen, D. W. K. Ng and R. Schober, "An overview of sustainable green 5G networks," IEEE Wireless Communications, vol. 24, pp. 72-80, August 2017.

2) Z. Hasan, H. Boostanimehr and V. K. Bhargava, "Green cellular networks: A survey, some research issues and challenges," IEEE Communications Surveys & Tutorials, vol. 13, pp. 524-540, Fourth Quarter 2011.

Dr S.A.H.A. Suraweera
Senior Lecturer,
Department of Electrical and Electronic Engineering,
Faculty of Engineering,
University of Peradeniya
himal@ee.pdn.ac.lk

Renewable Energy Education: From Kindergarten to University

Dr H.M.V.R. Herath

Our planet is at crossroads. On one side, with the continuous increase in world population and the spread of industrialization, as well as urbanization of nations, there is a huge increasing demand for energy. On the other side, with the burning of fossil fuels at ever increasing rates to satisfy energy demand, there is environmental pollution and climate change, which can threaten the very existence of the human civilization on the planet earth. If you add to that the fact that there is only a limited supply of fossil fuels, which may run out in the next 40-50 years, the picture becomes frightful. But, if you consider the fact that the Sun is our primary source of energy, and that all the other energy sources are secondary to the Suns energy, earth dwellers will have sufficient energy to carry out their activities for another billion years. In order to harness that energy, it is necessary to maintain the equilibrium of our ecosystem.

Use of renewable energy sources, such as solar energy, wind energy, and hydro energy can be considered as the long term solution to energy scarcity and climate change. Renewable energy sources have unlimited supply capacity, and do not contribute to greenhouse gas generation. Furthermore, energy generation through renewable sources has only a limited contribution to environmental pollution.

Apart from the technical issues related to connecting renewable energy sources on a large scale to the power grid, the main barrier with regard to renewable energy penetration in Sri Lanka is the lack of awareness about renewable energy among the general population, and the scarcity of skilled engineers and technicians necessary to sustain the renewable energy industry. Therefore, renewable energy education in Sri Lanka should be geared towards increasing awareness about renewable energy among the general public as well as producing skilled engineers and technicians

Figure 01 : Middle school pupils participate in hands-on activities on wind energy

necessary to sustain the renewable energy industry. It is necessary to look into how renewable energy education can be planned and designed to achieve such objectives. In order to inculcate awareness about renewable energy among the general populace it is essential that concepts such as sustainability, environment protection, and responsible use of natural resources be introduced as early as possible in the curricula. It may come as training the kindergarten children in the practice of separating household waste that can be recycled, or teaching the primary school children the practice of switching off unnecessary lights. It is easy to train small children to reuse things so that resources can be better utilized, and carbon footprint minimized. Attitudes of small children can be easily molded to be environmental and sustainability conscious.

Middle school (grades 6 to 11) science and civics curricula offer a valuable opportunity to deliver sustainable energy education to children, who are in the process of forming their opinions and attitudes. Concepts related to environmental protection, sustainability, and climate change can be explained in depth in those subjects. For example, basic knowledge on how a house or a building can be designed to have a minimum carbon footprint can be shared at the middle school level. First steps towards technical education related to renewable energy can be taken at the middle school level. Concepts related to heat, power, energy, electricity, and energy storage are already included in the middle school science curriculum. It would be beneficial if the concepts related to energy conservation and energy conversion are discussed at a basic level in the middle school. Most importantly hands on activities related to solar energy, wind energy, and other renewable energy sources can be integrated to the science curriculum. With participation in hands on activities, students could develop an interest towards renewable energy generation.

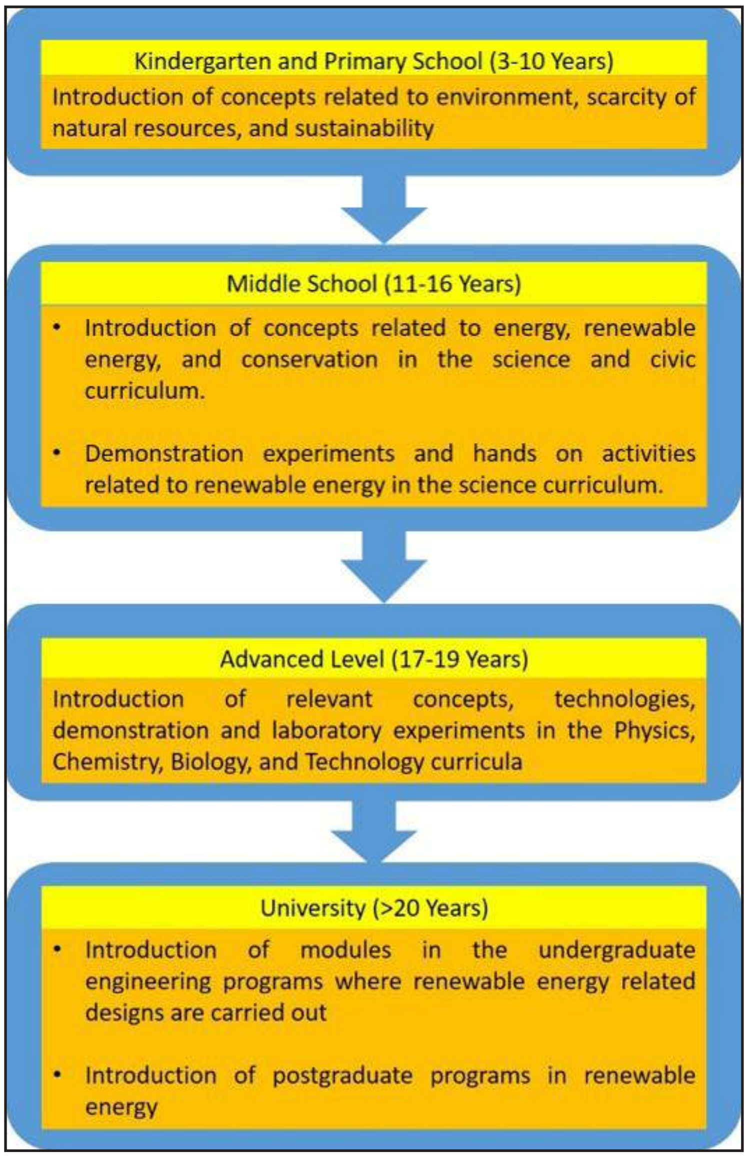


Figure 02 : Different stages of renewable energy education

In depth exploration of fundamental principles related to renewable energy can be done in the advanced level curriculum. Subjects such as Physics, Chemistry, Biology, and Technology are perfect vehicles to deliver such contents. For example, fundamental physical principles related to harnessing of solar, wind, and geothermal energy, can be discussed in the Physics curriculum. It is possible to discuss fundamental principles related to electro-chemical energy storage in the Chemistry curriculum. Biomass energy related fundamental principles can be discussed through Chemistry and Biology curricula. The technology stream is geared to producing technologists for future industries. As such, it would be possible to deliver system level knowledge related to renewable energy through the technology curriculum. Parallel to the above modifications, laboratory experiments and demonstrations need to be introduced to cement the knowledge. Any of above mentioned modifications to curricula need to be done in such way that the modifications do not harm the integrity and cohesion of the syllabus.

A student who has successfully completed school education, and is dreaming of entering into the renewable energy industry, should be able to fulfill his or her ambition by following an undergraduate engineering programme. In order to ensure that such a dream becomes a reality, undergraduate engineering curriculum should consist of modules where students develop their skills in designing renewable energy generation and distribution systems. The traditional electrical, mechanical, or chemical engineering curricula consists of a great deal of fundamental engineering knowledge that is necessary to work in the renewable energy industry. But, new modules are necessary to introduce students to design and deployment of renewable energy systems. With that knowledge students will be able to directly enter into the renewable energy industry after graduation. Specialized modules could be on PV system generation, biomass energy systems, etc.

Figure 03 : School children participate in hands-on activities on solar energy

Novel renewable energy systems are not as mature as traditional energy generation systems. Therefore, a great deal of research is going on to improve the efficiency and effectiveness of such renewable energy systems. Postgraduate programmes are a useful way of carrying out research on renewable energy. Sri Lanka does not have postgraduate programmes dedicated to renewable energy systems. This is one area that universities should be looking into when introducing new postgraduate programmes related to engineering. Even without dedicated postgraduate programmes, research on renewable energy can be carried out with available local expertise. In order to update the workforce in the renewable energy industry with state of the art knowledge, experts need to carry out continuous professional development activities. Universities are capable of organizing such programmes with the help of relevant experts in the academic staff.

A kindergarten to university approach is necessary for renewable energy education. Successful implementation of such an approach will result in an attitude change of the society towards renewable energy, environmental conservation, and sustainability. Furthermore, this approach will provide qualified engineering professionals who can drive the renewable energy industry forward.

Dr H.M.V.R. Herath
Senior Lecturer
Department of Electrical and Electronic Engineering,
University of Peradeniya
vijitha@eng.pdn.ac.lk

What have you learnt from the Vidurava 2020 July - September Q3 Issue? Scan your own memory!

1] Energy In The Modern World

True or False?

1. At some time in the future the costs of the extraction of oil and gas will become so high as to limit their use.
2. The concentration of existing greenhouse gases in the earth's atmosphere causes the temperature of the earth to be maintained at a level unsuitable for life.
3. Climate change brought about by the emission of CO2 from burning fossil fuels is a major driver of energy policy in many countries.
4. Renewable energy sources have a much lower energy density than fossil fuels and so the generation plants are smaller and geographically widely spread.
5. From around 1990 there has been no revival of interest in connecting renewable generation to the electrical power network, which demands some degree of integration, automation and control.

2] Control of Powered Motion : The Unsung Driver of Human Civilization Through Harnessing of Renewable Energy

True or False?

1. The first evidentially known classes of practical powered motion enabled, and enhanced through automatic control (at least the ones which are properly documented in the western world), were the applications in clockwork, water-wheel and wind-mill.
2. Harnessing the energy contained in wind and water wheels has been a common strategy to accomplish the energy needs of industry since antiquity.
3. The fluctuation of the separation of grinding-stones was not something that could be adjusted by hand.
4. In the days of Mead, the fluctuation wind speed only affected quality of flour and bread, but now it has more dire consequences in wind power generation.
5. Even from the times of using animals such as cattle, horses, donkeys or elephants to realize a task, it was not necessary to "control" the motion.

3] Geopolitics of Renewables : Thinking ahead towards Smart Renewable Energy

True or False?

1. The term 'geography' not only relates to factors such as area, natural resources, climate, and topography but also to factors such as demography, culture, technological resources and history.
2. The Geopolitical situation of the 18th and 19th centuries led to the rapid industrialization of many western countries.
3. Most recent projections show that renewable energy would not become the leading source of primary energy consumption by 2050.
4. Electrification of 'hard to electrify' sectors such as transport and heavy industry is one such new frontier of research that focuses on consumption-side adaptation.
5. What is interesting about technology driven geopolitical waves is that they have always not given the opportunity to countries not rich in natural resources to become players in the geopolitical stage.

4] DC Returns With Renewables

True or False?

1. To supply electric power to the lights within Pearl Street's service area, Edison and his team developed the 27-ton "Jumbo" constant-voltage dynamo.
2. The invention of the ac transformer by Nikola Tesla permitted the economic and efficient long-distance transmission of electric power at high voltages.
3. There is no limit to the distance that bulk ac can be transmitted unless some form of reactive compensation is employed.
4. For large offshore sites that are far away from the main grid and generate 100s of MW of power, HVDC has become a preferred choice.
5. With an output of 800 megawatts (MW), BorWin2 is the last large-scale offshore connection that TenneT has implemented.

5] Green Communications for a Low-Carbon World

True or False?

1. Today, a variety of wireless systems are in use and there has been an increasing demand for high throughput data services in indoor environments as well as outdoor environments.
2. With the introduction of every generation of cellular systems, we have witnessed shrunken cell sizes.
3. Utilized since the inception of wireless days, power control is an ineffective mechanism to prevent interference among receivers.
4. As one of the essential parts of a base station, radio consumes more than 80% of base station's energy requirement.
5. It is worthwhile to note that data exchange in the grid creates no new security problems and privacy issues that should be addressed.

6] Renewable Energy Education : From Kindergarten To University

True or False?

1. Renewable energy sources have unlimited supply capacity, and do not contribute to greenhouse gas generation.
2. It is easy to train small children to reuse things so that resources can be better utilized, and carbon footprint minimized.
3. It would be beneficial if the concepts related to energy conservation and energy conversion are not discussed at a basic level in the middle school.
4. In depth exploration of fundamental principles related to renewable energy can be done in the advanced level curriculum.
5. New modules are not necessary to introduce students to design and deployment of renewable energy systems.

Answers

01) 1. True, 2. False, 3. True, 4. True, 5. False
02) 1. True, 2. True, 3. False, 4. True, 5. False
03) 1. True, 2. True, 3. False, 4. True, 5. False
04) 1. True, 2. True, 3. False, 4. True, 5. False
05) 1. True, 2. True, 3. False, 4. True, 5. False
06) 1. True, 2. True, 3. False, 4. True, 5. False

National Science Foundation
47/5, Maitland Place
Colombo 07