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IEEE POWER ENGINEERING SOCIETY
ENERGY DEVELOPMENT AND POWER GENERATION COMMITTEE

Electricity Challenges for Africa Towards 2010 and Beyond

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Working Group on African Electricity Infrastructure Experience and HVDC Promotion[1]

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Sponsored by: International Practices for Energy Development and Power Generation

Chairs: Alison Chikova, SAPP Chief Engineer, SAPP Coordination Centre, Harare, Zimbabwe
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Track: Utilization of Energy Resources

INTRODUCTION

On behalf of the Energy Development and Power Generation Committee, welcome to this Panel Session on Electricity Challenges for Africa Towards 2010 and Beyond

Electricity supply remains a challenge the world over due to the capital-intensive nature of the generation and transmission investments required. This Session focuses on the present status and future prospect of electricity infrastructure from the viewpoint of Generation and Transmission Development, Global Deregulation trends and policies, advances in Global Research and Development (R & D) and strategies to influence the integration into the Global transition to knowledge based economies in Africa. The panel will therefore evaluate and update models and policies that are near term, mid term and long term.

Interconnection of electric power systems of regions, states and individual territories as previously recognized by this body is acquiring a growing scale of importance in world practice. Examples of this influence and studies to date will be presented. Presentations will continue to be focused on the projected development of regional power pools as a development strategy while taking into account the importance of distributed generation in this strategy. There are many benefits of this tendency that continue to be examined to influence development policies because of the so-called system effects that lead to improving economical, ecological and technological efficiencies of the joint operation of electric power systems. Modeling developing regional grids remains core to the strategy of wider institutional integration, and in particular academia where core analytical skill sets critical to knowledge base economies reside.

Africa is facing a major challenge in meeting its electricity requirements. The different regions in Africa are working tirelessly to meet the energy requirement of the continent. In sub

[1] Document prepared and edited by T J Hammons

Saharan Africa alone, The Southern African Power Pool has a population of over 240 million people. Only 40% have access to electricity. The demand is rising at a rate of 3.6 % per annum and surplus generation capacity is running out. The Southern African Development Community has an installed capacity of 53,000 MW of which 43,000 MW is dependable. This is against a backdrop of a regional demand of 41,000 MW. To maintain good reliability of supply and adequate reserve margins new plant is needed.

The countries in the region are developing rehabilitation, short term, medium term and lone term projects. Africa is a very favorable region for electric power grid creation and using the above system effects on account of different levels of economic development in different countries of the region, different placement of fuel and energy resources, and consumers, etc. Therefore, the analyses of the present status and prospective trends of African Electricity interconnections and efforts to improve efficiency and bridging the digital divide are very important problems.

The challenge for Africa is immense and 2010 is a testing period to rise to the occasion and assure the World that Africa's electricity supply is reliable.

The Session presents some results of studies in this area at this time.

The Panelists and Titles of their Presentations are:

1. Tom Hammons, Pat Naidoo, Alison Chikova and Bai Blyden. Electricity Challenges for Africa Towards 2010 and Beyond (Invited Panel Presentation Summary 08GM0212).
2. Pat Naidoo, Senior General Manager, Eskom, South Africa and N. M. Ijumba, University of KwaZulu Natal, South Africa. A Novel Approach to Providing on Route Power Supplies to Rural and Urban Communities in Close Proximity to Extra High Voltage DC Transmission Lines (Invited Panel Presentation Summary 08GM1427).
3. Bai K Blyden, Wei-Jen Lee, and Virgil D. Perryman Jr.. An Assessment of Microgrid based Integratable Technologies as a Strategic Dynamic for Accelerated and Sustainable Economic Growth. (Invited Panel Presentation Summary 08GM1652).
4. Akilagpa Sawyerr, Secretary-General of WAPP, Association of African Universities. Knowledge and Development in Africa: What Price Access? (Invited Panel Presentation Summary 08GM1621)
5. P. Naidoo, Senior General Manager, Eskom, South Africa, and R. Marcus, Da Vinci Institute of Technology, Johannesburg, South Africa. Towards Developing a New Model for the Pricing of Electrical Energy in Continuously Changing Environments (Invited Panel Presentation Summary 08GM1421)
6. Paul V. Preckel, Frederick T. Sparrow, Brian H. Bowen, Zuwei.Yu, Douglas J. Gotham and Zhijun Yang, Power Pool Development Group, Purdue University, West Lafayette, IN, USA. Preserving Low Cost Electricity while Improving the Riverine Environment: A Case Study of Ghana's Akosombo Dam (Invited Panel Presentation Summary 08GM0849)
7. Satoshi Morozumi, Nobuyuki Inoue, Yasuyuki Arashiro, Yasushi Chiba, and Toshiyasu Iwasak, The New Energy and Industrial Technology Development Organization (NEDO), Japan. Strategies and Status of Grid-connection Technology Development in the New Energy and Industrial Technology Development Organization (NEDO) (Invited Panel Presentation Summary 08GM0291)
8. Pat Naidoo, Senior General Manager of Transmission Company, ESKOM, Johannesburg, South Africa and Alison Chikova, SAPP Chief Engineer, SAPP Coordination Centre, Harare, Zimbabwe SAPP Challenges towards meeting the 2010 Electricity Challenges (Invited Discussion)
9. Lawrence Musaba, Coordination Centre Manager, Southern African Power Pool (SAPP), Harare, Zimbabwe and Alison Chikova, SAPP Chief Engineer, SAPP Coordination Centre, Harare, Zimbabwe Experiences of Projects for Interconnecting Africa Challenges (Invited Discussion)

10. Alison Chikova, SAPP Chief Engineer, SAPP Coordination Centre, Harare, Zimbabwe. Long Term Power Contracts for Meeting the Electricity Requirements of Southern Africa (Invited Discussion)
11. Invited Discussers.

Each Panelist will speak for approximately 30 minutes. Each presentation will be discussed immediately following the respective presentation. There will be a further opportunity for discussion of the presentations following the final presentation.

The Panel Session has been organized by Alison Chikova (System Studies Supervisor, Southern African Power Pool, Harare, Zimbabwe); Pat Naidoo (Senior General Manager of Transmission Company, ESKOM, Johannesburg, South Africa**)**; Tom Hammons (Chair of International Practices for Energy Development and Power Generation IEEE, University of Glasgow, UK) and Bai Blyden (Consultant, BBRM Group, Elk Grove, CA**,** USA).

Tom Hammons, Pat Naidoo, Alison Chikova and Bai Blyden will moderate the Panel Session.

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BIOGRAPHIES

Thomas James Hammons (F'96) received the degree of ACGI from City and Guilds College, London, U.K. and the B.Sc. degree in Engineering (1st Class Honors), and the DIC, and Ph.D. degrees from Imperial College, London University.

He is a member of the teaching faculty of the Faculty of Engineering, University of Glasgow, Scotland, U.K. Prior to this he was employed as an Engineer in the Systems Engineering Department of Associated Electrical Industries, Manchester, U. K. He was Professor of Electrical and Computer Engineering at McMaster University, Hamilton, Ontario, Canada in 1978-1979. He was a Visiting Professor at the Silesian Polytechnic University, Poland in 1978, a

Visiting Professor at the Czechoslovakian Academy of Sciences, Prague in 1982, 1985 and 1988, and a Visiting Professor at the Polytechnic University of Grenoble, France in 1984. He is the author/co-author of over 350 scientific articles and papers on electrical power engineering. He has lectured extensively in North America, Africa, Asia, and both in Eastern and Western Europe.

Dr Hammons is Chair of International Practices for Energy Development and Power Generation of IEEE, and Past Chair of United Kingdom and Republic of Ireland (UKRI) Section IEEE. He received the IEEE Power Engineering Society 2003 Outstanding Large Chapter Award as Chair of the United Kingdom and Republic of Ireland Section Power Engineering Chapter (1994~2003) in 2004; and the IEEE Power Engineering Society Energy Development and Power Generation Award in Recognition of Distinguished Service to the Committee in 1996. He also received two higher honorary Doctorates in Engineering. He is a Founder Member of the International Universities Power Engineering Conference (UPEC) (Convener 1967). He is currently Permanent Secretary of UPEC. He is a registered European Engineer in the Federation of National Engineering Associations in Europe.

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Alison Chikova is Chief Engineer of the Southern African Power Pool. He holds a Master of Science Degree from Kharkov Polytechnic Institute, in Ukraine, having specialised in Electrical Power Networks and Systems. He graduated in 1992. H worked for the Ministry of Energy as an Energy Research and Development Officer. In 1995 he moved to the power utility in Zimbabwe where he was heading the Generation Planning Unit.

In 2001 he joined the Southern African Power Pool where he is responsible for technical issues including System Studies for the Interconnected SAPP Grid. He is also taking part in the development of a competitive and ancillary services market in SAPP. He has made significant contributions in transmission pricing arrangements for the Power Pool.

He is a Chartered Engineer and a Member of IEEE (USA) and IET (UK). His contact E-mail address is: Email: Alison.Chikova@sapp.co.zw

Bai K Blyden, Engineering Consultant, BBRM Group, LLC, USA. Bai Blyden received the degree of MS.EE from the Moscow Energetics Institute in 1979. Specializing in Power Systems, Generation and Industrial Distribution Systems with a minor in Computers. He is currently a Project Manager with the Cummins Power Generation Group responsible for Distributed Generation CoGen projects in California where he resides. Mr. Blyden has worked on over thirty power plants and their associated interconnections throughout his career in various capacities of Electrical Systems design, operations planning, management and construction. He has held consulting staff positions with various Utilities such as TVA, PG&E, The New York Power Authority, Entergy and TXU. He has also been a Project Engineer for major AE firms in the Power industry including Bechtel, Asea Brown Boveri, Stone & Webster and Dravo/Gibbs & Hill. While at ABB Mr. Blyden successfully led engineering teams that prepared Kansas Gas & Electric 950 MW Wolf Creek Nuclear Plant and Georgia Power's 2 x 1215 MW Plant Vogtle for Nuclear Regulatory Commission Electrical Distribution Safety Functional Inspection audits (EDSFI). He most recently served as a Project Manager on the CALPINE California Emergency Peaker Program which planned and managed the construction of eleven (45MW) emergency GE LM6000 gas turbine Peaker units around Silicon valley during the 2001 CA Energy crisis. He is a member of the IEEE International Practices Subcommittee and serves as consultant to GENI (Global Energy Network International). Bai Blyden is the author of several papers on African Energy Development published in various IEEE publications (1983-2004). He introduced the theoretical concept of a 'Dynamic Parameter', which he presented at MIT and at the IEEE Systems, Man and Cybernetics society conference, 1992 relating to Expert Systems and Artificial Intelligence applications for Power Plants. He has lectured extensively on African Energy Development issues to Institutions and more recently to Investment groups. Mr. Blyden is an early advocate of an Integrated African Grid and presented a conceptual framework and technical analysis for a centralized African Power pool with links to North Africa at the first IEEE Region 8 conference held in Nairobi, Kenya, December 1983.

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2. A Novel Approach to Providing on route Power Supplies to Rural and Urban Communities in Close Proximity to the Extra High Voltage DC Transmission Line

P. Naidoo*[2] and N.M. Ijumba**

Abstract: Extra high voltage DC transmission is planned for the many power corridors of the Continental African Grid. These lines will traverse the countryside and will pass over many rural and urban communities. These communities will in general have no formal access to grid electrical energy. Access to electrical energy for the basics of light and heat will provide a better quality of life for all. It is thus an expectation of the engineering design that such access is provided affordably. Laboratory based studies of HVDC sources have shown that conventional corona cages can capture the corona energy and be made available as a continuous energy source. The low levels of the energy source may require that the energy be employed in association with a conventional battery or solar energy source; the constant is that the corona energy is always available and will serve as a continuous recharge for the battery employed. This arrangement provides a unique and novel approach for the use of the corona energy, which would otherwise be lost to atmosphere radiation. There is no charge for the otherwise lost energy and every tower of the DC circuit could have the corona cages installed and built at time of line construction. The dimensions of the cage can be optimized to serve other DC line requirements.

Keywords: HVDC Transmission, Corona, Electric Field Effects.

1. Introduction

Power line designers and transmission engineers are continuously challenged to provide on route power supplies to generally small load rural communities. It becomes extremely embarrassing to negotiate with the owners or inhabitants of the servitudes the rights for power transmission with all its quality of life benefits; then abruptly to decline the requests for local power supplies on the basis of technical difficulties or un-affordability of appropriate technology for the tapping of electrical energy from the overhead power lines.

For the Western Power Corridor under feasibility study, this potential issue arose and the shareholders of the company being the participating national utilities and governments are keen that on route power supplies be made available to rural communities. In addition to the shareholder request, telecommunication engineers have noted that given the very long distance of power transmission, expected to be in the 3000 to 4000 km range, on route power supplies will be required for power line carrier and fiber optic based telecommunications systems.

Many engineers have explored this topic of tapping from high voltage overhead transmission lines and many have tabled proposals. Latest voltage sourced converter technology from the IGBT laboratories show that many megawatts can be extracted from high and extra high voltage DC transmission lines.

For the research study, the focus is on the small watt or kilowatt type rural load; generally scattered along the route of the transmission line having high or extra high DC voltages. It is known that for high or extra high DC operating voltages, the high electric fields promote corona

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generation. As part of the on going investigations into corona generation, corona audible noise levels, corona power losses and corona radio interference; the HVDC Center at the University of KwaZulu Natal built a purpose made corona cage for small air gap studies. The cage was built based on the earlier work of Maruvadu [1].

A photo of the corona cage is given in figure 1 and samples of electric fields calculated at different operating voltages are given in figures 2, 3 and 4. The test results are given in Table 1.

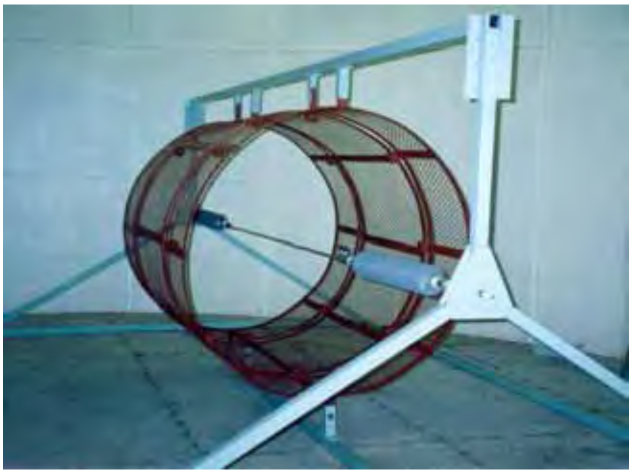

Figure 1. DC Center Corona Cage at the University of KwaZulu Natal

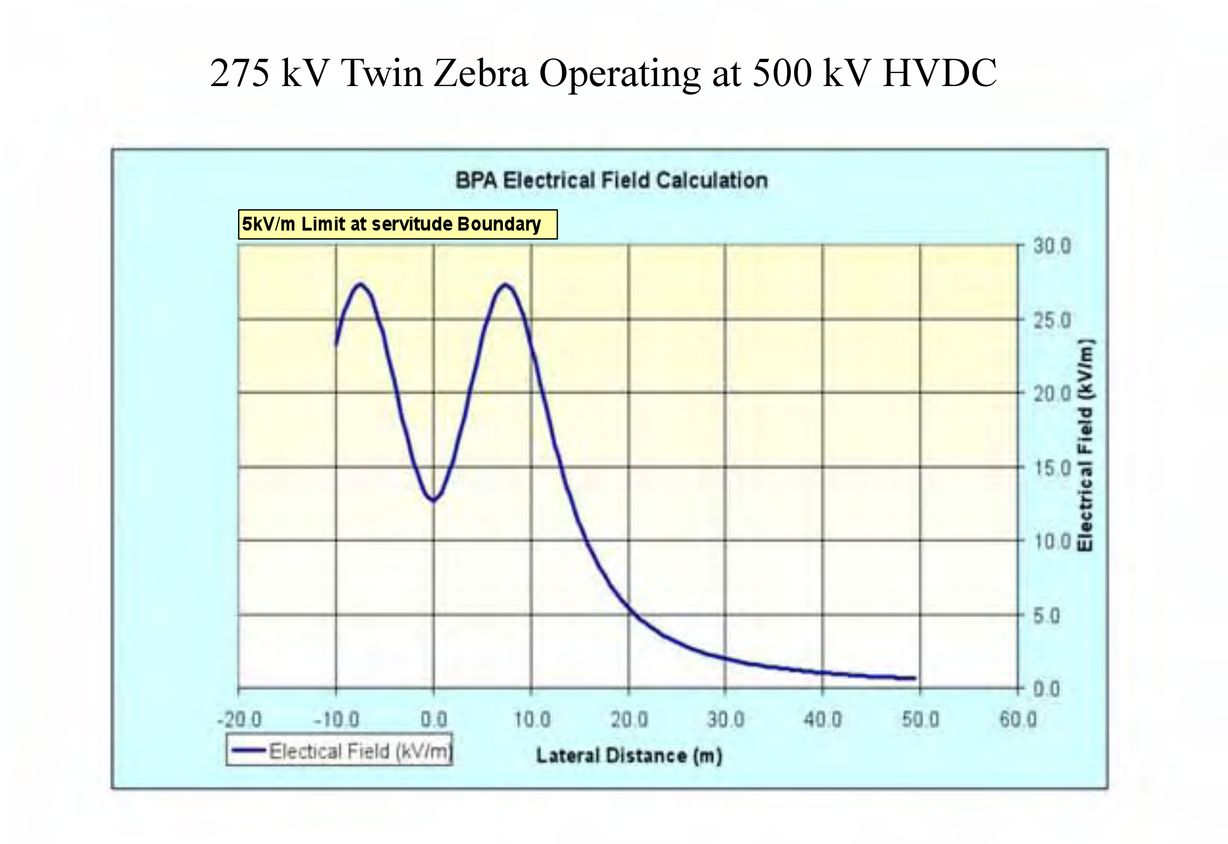

Figure 2. 500 kV HVDC Generated Electric Field on a twin zebra bundle conductor arrangement.

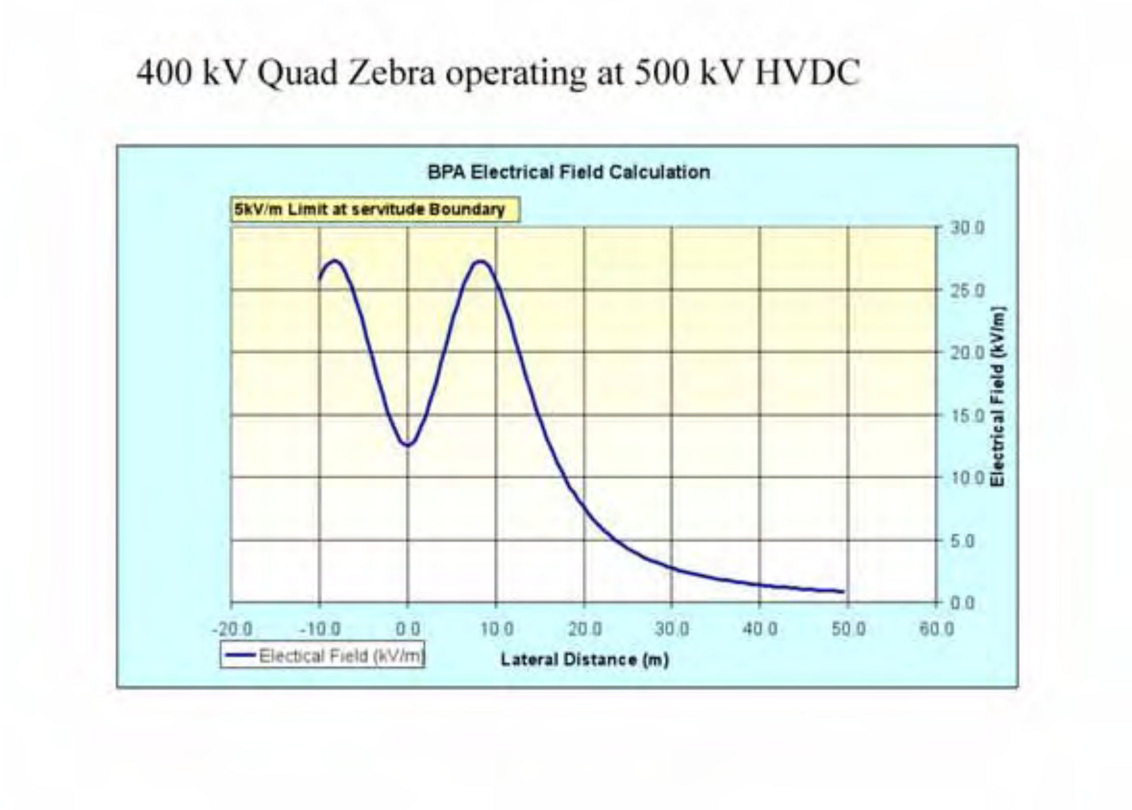

Figure 3. 500 kV HVDC Generated Electric Field on a quad zebra bundle conductor arrangement.

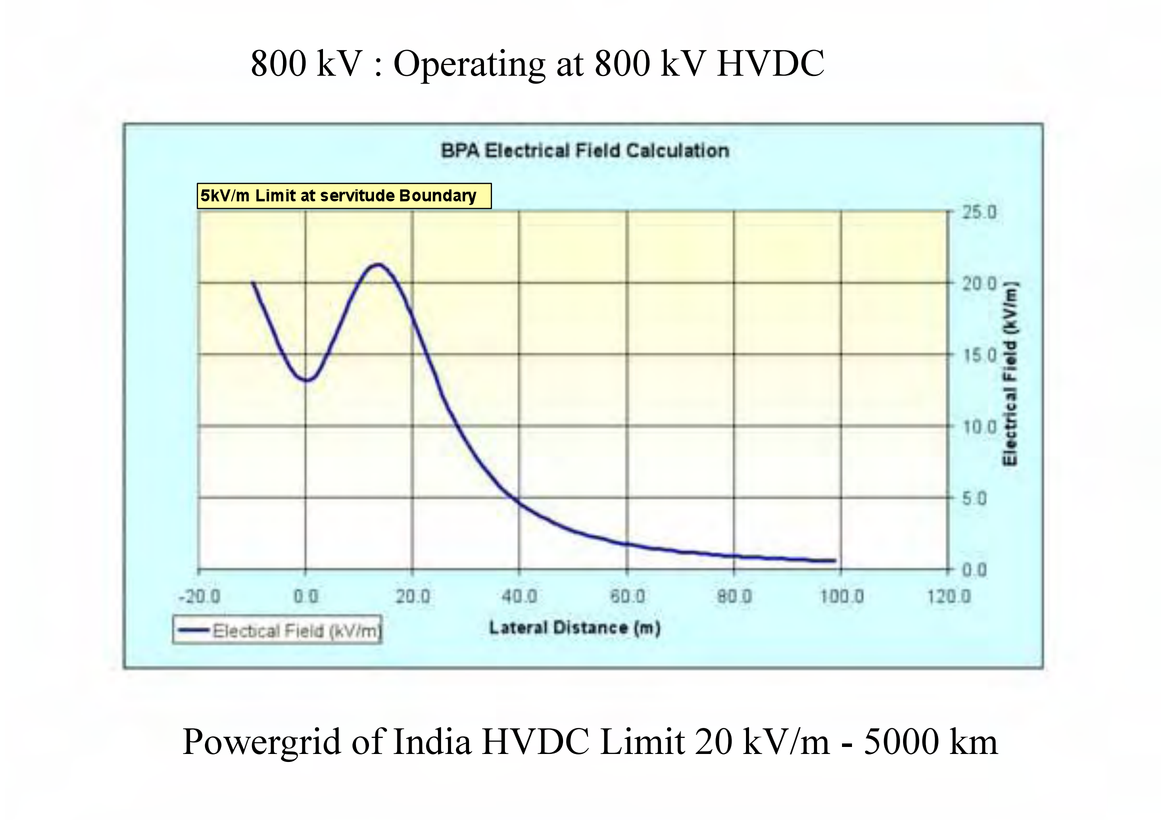

Figure 4. 800 kV HVDC Generated Electric Field on a six bundle zebra conductor arrangement.

From the calculations performed, we note that in the immediate vicinity of the conductor bundle, we have adequate corona energy. As we move towards the edge of the servitude, the corona energy attenuates and is not available for external loads.

Based on a simple single conductor arrangement, the corona energy available in the immediate vicinity of the conductor is experimentally evaluated.

2. EXPERIMENTATION TO EVALUATE POTENTIAL OF CORONA ENERGY FOR SMALL LOAD APPLICATION.

The DC test voltage source was gradually increased and the corresponding leakage to the frame current was measured. These processes continued until breakdown occurred across the small air gap at the air gap critical withstand voltage level. The experimental results are given in table 1.

Table 1: Experimental Results

Test Voltage DC Negative Polarity	Measured Leakage Current
10	0
20	0
27	0,1 uA
34	0.12 uA
40	0,15 uA
49,5	0,2 uA
60	0,42 uA
70	1,14 uA
80	3,4 uA
90 kV Corona Audible	9,25 uA
100	16,63uA
110	22,8 uA
120	38,4 uA
130	52,34 uA
140	78,3 uA
150	95,6 uA
160	125,9 uA
170	161 uA
180	184 uA
190	217 uA
200	255 uA
210	295 uA
220	326 uA
230	350 uA
240	383 uA
243 kV Breakdown of Air Gap	

3. CONCLUSION

It is clear from the results that once audible corona occurs, corona power loss occurs and continues to increase with increasing levels of test voltage. Thus at a selected operating voltage, the corona power loss will be present and can be employed to provide the “continuous trickle charge” for an alternative energy source that powers the on route application. This method of tapping energy from a high voltage DC line has practical benefits and requires further work.

4. REFERENCES

[1] Sarma P. Maruvada. ***"Corona Performance of High Voltage Transmission Lines."*** Research Studies Press LTD. Baldock, Hertfordshire, England 2000 ISBN 0 86380 254 0.

BIOGRAPHY

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3. An Assessment of Microgrid based Integratable Technologies as a Strategic Dynamic for Accelerated and Sustainable Economic Growth.

Bai K Blyden, Wei-Jen Lee, and Virgil D. Perryman Jr. An Assessment of Microgrid based Integratable Technologies as a Strategic Dynamic for Accelerated and Sustainable Economic Growth.

Abstract---This paper seeks to further proposals previously submitted for a balanced Distributed Generation strategy through modified microgrids as part of the various regional energy programs underway in Africa. This paper also points to R&D advancements in various technologies focused on energy sustainability. Our evaluation suggests that many of these technologies integrated even at microgrid-powered levels can provide an efficiency of service beyond rural communities to include large urban centers. This paper will attempt to show that these integrated systems can serve as the drivers for efficient municipal town planning systems, resource management and growth catalysts. Advanced Refrigeration systems using low-grade heat as well as advanced technologies such as plasma gasification through a miniaturization process have shown can be supported by small DG systems. The advantages for municipal solid waste management, fuel production conversion from any carbon based feedstock and ecological remediation help establish new paradigms for conservation, municipal planning and development particularly in emerging economies. Several models based on previous publications around the development of modified micro grids are discussed to illustrate possibilities. This development will serve as primary building blocks for future system expansion. Issues regarding the potential resources for hybrid distributed generation and reliability of power supply are addressed.

Keywords: Microgrid, Renewable energy, Biomass, Integrated sustainable development.

1. INTRODUCTION

The availability of affordable and reliable energy is one of the most crucial requirements for economic development and modernization of developing countries. This is particularly important in Africa, a continent where the majority of people are still dependent on fuel wood for their energy requirements. With a population of 13.4% of the world and a land area of 15%, Africa has only 2% of the world's industrial capacity. Its per capita income is only 15% of the world average and only consumes 3% of world energy. Today, less than 15% of Africa's population has access to electricity and where much of the available supply is unreliable. A Survey of Energy Resources conducted by the World Energy Council (WEC) in 2004 shows that Africa has more than enough to satisfy all its energy requirements. These include 7.1% of the world's known oil reserves, 7.5% of the gas, 10.6% of the coal and 13% of the hydro. However, the resources are not evenly distributed within the continent. For example, Oil and natural gas are found mainly in the northern and western parts of the continent. Gas usage is limited. Egypt and Algeria produce 98.5 billion cubic meters of Africa's total production of 116.8 billion cubic meters. Almost 96% of the coal is produced in South Africa, Hydro is concentrated mainly on the Congo, Nile, Niger, Volta and Zambezi rivers. Therefore, regional cooperation and integration through energy pooling and cross-border energy trading would help economic development of the continent. This can be achieved through promoting cross-border interconnection of electricity grids and gas pipeline networks and the joint development of new electrical generation projects. This paper however is focused on small, midsize microgrids (1MW-5MW) capable of being integrated with enabling advanced technologies which in turn address a number of the critical quality of life social requirements such as fuel, sanitation remediation, water resource management and refrigeration for small towns as well as large urban population centers.

2. REGIONAL INITIATIVES

The electricity sector in particular, has introduced the concept of Pan-Africa Interconnections to facilitate energy pooling and cross-border energy trading as illustrated by the conceptual backbone transmission grid shown in Fig. 1. At present he main development includes Northern Africa (Mediterranean Ring Project), Western, Eastern and Southern Africa.

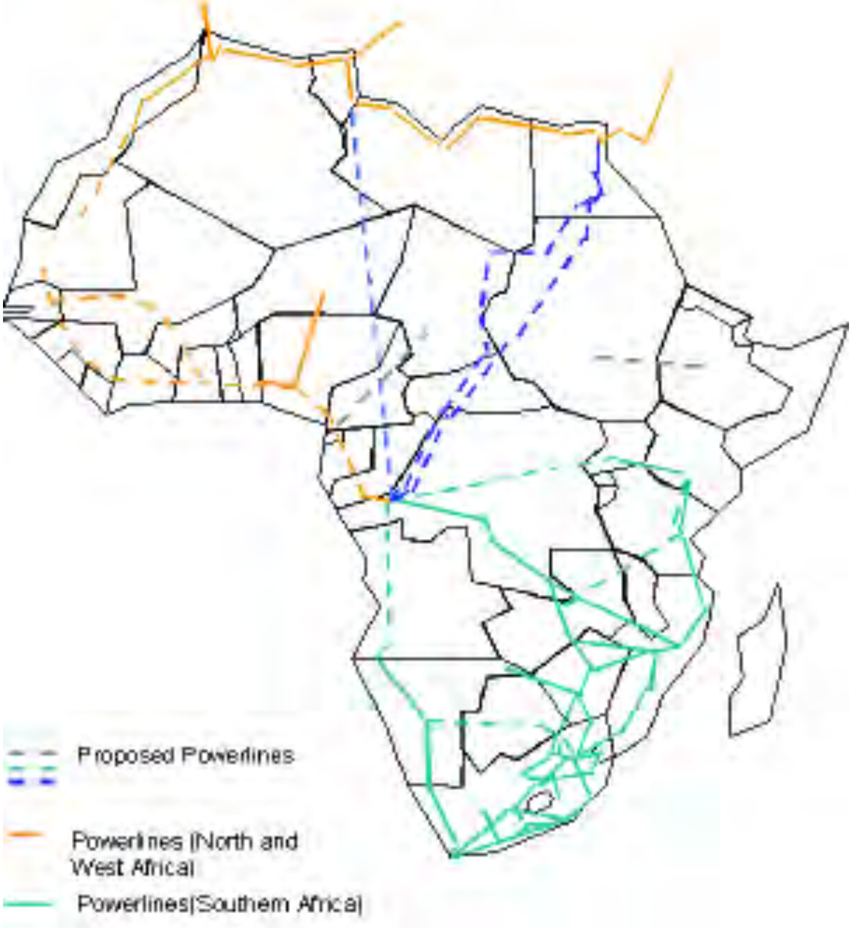

Fig. 1. Pan-Africa Interconnection

3. SELECTED TECHNOLOGIES IN MODIFIED MICROGRIDS

Most of the current programs emphasize photovoltaic technology. While being the most environmentally friendly energy resource at present, Photovoltaic is not a controllable source and can only provide limited energy to small towns and villages unless these systems are equipped with energy storage devices. Further, the per watt installation cost is still much higher than traditional generation facilities [1, 2]. These systems may also present problems for future grid connection if not looked at holistically as recommended in [7-9]. previously stated study emphasizes a Bottom-Up approach through an evaluation of autonomous or non-autonomous Micro Grids consisting of a variety of small DG resources which can serve as basic building blocks for future system expansion. Issues such as system reliability, security, stability and controls associated with the transition and integration of Micro Grids to larger systems for better optimization and efficiency are made inherent in their designs.

To further the productive efficiency of these systems the following technologies are examined under this study.

1. Advanced Refrigeration systems from low-grade heat sources≤250F.
2. Advances in Fischer Tropsch Gasification technology
3. Low Grade Heat to Electricity systems

3.1 Heat Pump

Current heat pump technologies can be utilized for hot water heating and chilling. It supplies ai conditioning or refrigeration at the cold end, and which uses all the reject heat (gas heat plus cooling duty to heat hot water. It uses same fuel as other hot water heaters but requires less fuel that presents savings or both electricity and fuel. Its advantages are that it can be used for dairies, hospitals, hotels, laundries, mea processors, poultry processors, breweries and beverages.

Fig. 2. Sample of a 100T Heat Pump Unit

One of the heat pump facilities has been installed at a poultry processing plant in central California. This technology provides hot water and chilled water at roughly double the energy efficiency and almost half the cost of any conventional technology. The sequence of preparing poultry for market is regulated by the U.S. Department of Agriculture, and includes a scalding step using 140 degree F hot water, followed in short order by chilling with 33 degree F chilled water. The plant that is hosting this demonstration processes 50,000 birds per hour for 15 hours each day. This requires a continuous flow of at least 190 gallons per minute (gpm) hot water and 190 gpm-chilled water. The hot water is produced from 80-psig steam from natural gas-fired boilers, and the chilled water is produced from an ammonia vapor compression refrigeration plant powered by electricity. At current utility rates ($10 gas and 9¢ electric), the plant spends $420K per year on natural gas to make the hot water, and $100K per year on electricity for the refrigeration to make the chilled water.

In view of the high projected benefit and reasonable cost, the Plant Manager agreed to host a demonstration project, and gave approval to proceed in mid-October, 2005. This demonstration unit is designed to supply 75-tons of chilling at the full temperature With a lesser temperature spread, made possible when only “pre-chilling” and “pre-heating” are required, and the existing equipment completes the chilling and heating, then the design capacity increases to 100-tons chilling. Initial operation has been at about 82% of design capacity, and measures have been identified which should increase capacity to 100%. Starting with the 69 degree F city water available at this site, 100 gpm is currently pre-chilled to 48 degree F, and 110 gpm is pre-heated to 121 degree F. According to the estimation, the $180K installation provides approximately $100K per year savings in natural gas and electric utilities [3].

3.2 Advanced Fischer Tropsch Synthesis

The Fischer-Tropsch (FT) process is a catalyzed chemical reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms. The principal purpose of this process is to produce a synthetic petroleum substitute, typically from coal or natural gas, for use as synthetic lubrication oil or as synthetic fuel. The procedure was based on revisiting the basic chemistry at the molecular level that has resulted in a powerful set of solutions for many of today's industries and sustainability challenges. The achievements are such that mini-refineries and processing plants can be rapidly deployed and easily deployed in tight urban areas that may have the greatest needs and or zoned appropriately. Various feedstock ranging from Plant and animal biomass to petroleum coke and heavy crude can be processed in these systems to produce a variety of synthetic fuels and other products. See Table 1 shows the conversion rates of different Feedstocks.

Fig. 3. Fischer Tropsch Plant

Recently, a technology has been proposed to combine the high temperature plasma gasification system while processing syngas used in the Fischer Tropsch Synthesis to remove and recover the Sulfur, vitrify it into inert slag as well as other impurities and heavy metals, and deliver to the FT reactor to produce the purest syngas available. As the results, the synthetic crude does not need the units at the refinery that use energy to remove Tars or Sulfur.

Equally important, other non-petroleum materials can be evaluated at the same facility as the Fischer Tropsch Synthetic Crude. The same refineries and distribution infrastructure would be able to process and distribute this ultra clean transport fuel, fertilizer or replacement for natural gas (DME) [4].

4. MUNICIPAL SOLID WASTE (MSW) AND BIOMASS ENERGY

Converting biomass energy into useable energy from this process of improved gasification has many environmental benefits. An increasing number of renewable energy projects using biomass have been developed. Most of these use waste products from agriculture, so they solve a waste disposal problem and, at the same time, create energy for use in homes, farms and factories.

Biogas can also be produced from livestock manure and human sewage. Farms where animals' graze and sewage plants are ideal places to produce energy from biogas. Waste peelings from food processing plants can also be used to produce biogas.

At present, direct wood burning is a major energy source for cooking for the average citizen with increasing detrimental effects to the environment. This is not the most efficient way to harvest energy from the nature. Converting the biomass to electrical energy can solve both energy and *Municipal Solid waste disposal problem at the same time.

Table 1: Conversion rates of Different Feedstocks

Feedstock	Yield
*1.5-2 Tons Municipal Solid Waste	1 Ton of DME
6000 T Day Plant Biomass	2000T of FT fuel

4.1 Waste Heat Generators

Some technologies are under development. One of them is the Waste Heat Generator (WHG). It converts geothermal and industrial waste heat or pressure into emission free electricity. One of the prototypes has employed 190-degree water to vaporize a low condensing liquid in a closed system. It then uses the pressure from that expanding gas to spin a turbine like device that drives its generator. With a projection cost per kilowatt under $2,000.00, a 20, 40, or 100 kilowatt units will be able to pay for themselves out of energy cost savings in less than 3 years. In addition, WHG can be placed local to heat sources, right on the plant floor, saving piping costs and reducing heat loss [5, 6].

5. THE INTEGRATED SUSTAINABLE SYSTEM DEVELOPMENT

The modern Microgrid power network architecture has incorporated the following power system and power electronics technologies:

- Advanced power network control techniques that allow for deployment of a wide range of DG and power network solutions into real-world applications
- An advanced power converter system to accept sources from different DG and storage devices. The distributed energy resources are able to interact directly over the power network to provide power sharing, power flow control, and voltage/frequency regulation.
- An open-platform energy management system that can provide remote monitoring, data collection and aggregation of distributed power systems into "dispatch able" blocks of capacity.
- A tie breaker with local/remote control function that manages the interface of Microgrid power systems to the utility, and allows for seamless transitions between stand-alone and grid-connected operation

Depending upon the loading condition and available resources, one or more local nodes could be formulated. See Fig.4 Each ring will be equipped with a local node controller for local optimization and control.

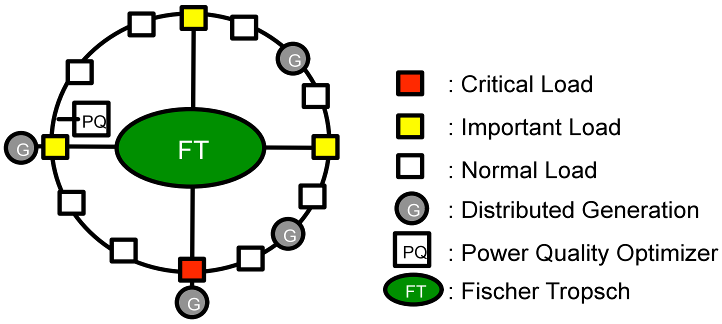

Fig. 4. Formation of Single-Ring Local Node

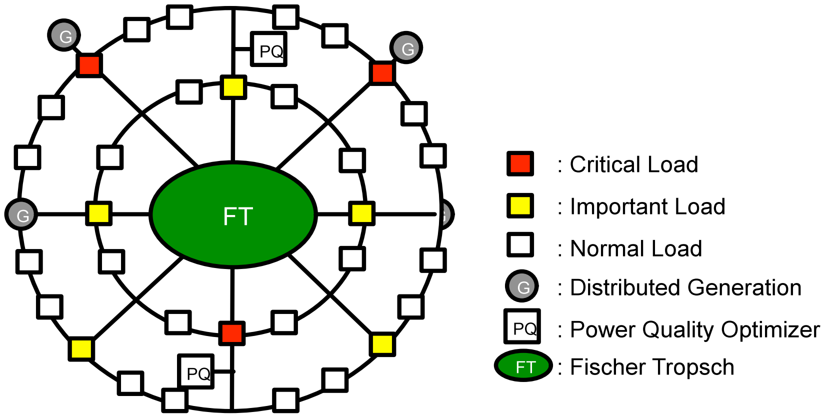

Fig. 5. Formation of an Integrated Sustainability System

Clusters of local nodes will then form a super node. Integrating the technologies under evaluation schematically shown in Fig. 5, offers higher system reliability furthering the optimization and efficiency of the whole system. Super nodes may equip larger scale distributed generation facilities and power quality controllers. The protection schemes between local nodes are similar to the branch protection within the local nodes. Depends upon the operation condition, the super node can be either autonomous or non-autonomous. During the grid connection operation, super node controller will communicate with SCADA/EMS of the local utility or ISO, local node controllers, distributed generators, and PQ optimizers. Super node will serve as basic building block of the future "Smart Grid".

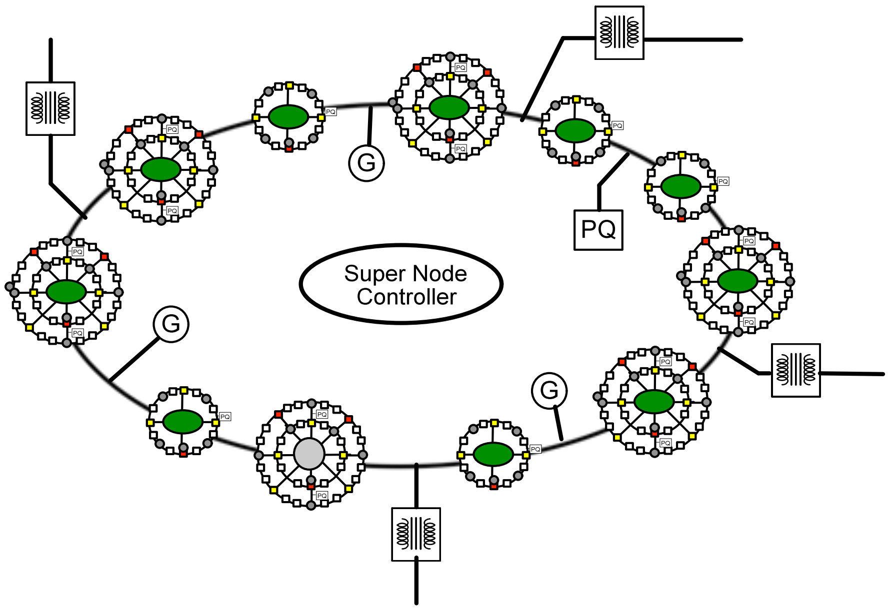

Fig. 6. Formation of a Super Node and Grid Connection

6. CONCLUSION

In a 2005 presentation ref.8 we proposed the "Olympic Ring" concept that is a metaphor for defining different Micro grids sizes to illustrate possibilities for a 'bottom-up' development. This paper aims attempted to assess how leveraging advances in some of these technologies across the spectrum of the economy can lead to a more efficient optimization of resources and advancement. The university bodies and technical schools from regional groupings within the Africa Union (AU) continue to be the focus of our recommendations and should be seen as incubators for creating "Energy Peace Corps" trained to develop service and manage these systems. The interregional partnerships and interface with major OEM's furthers a wider skill set development and involvement in their respective societies from the inherent social benefits of these applications.

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8. BIOGRAPHIES

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4. Knowledge and Development in Africa: What Price Access?

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[3]***Abstract*** - It is universally acknowledged that knowledge, in its application to production, organization, management and communication, is the driving force of development in the modern world. Information Communications Technology (ICT), in particular, the Internet has made a vast store of information widely available - but only to those able to access and turn it into useable knowledge!

In order to eradicate chronic poverty and achieve sustainable development, Africa has to be able to integrate its indigenous knowledge with modern global knowledge, and apply it in all areas of social life. In that connection, a critical constraint on Africa's development is the severe limitation on its access to and successful exploitation of modern knowledge; a limitation that is partly physical (infrastructure, equipment, etc.) and partly socio-legal (higher education capacity, intellectual property rights, etc.). The Association of African Universities, on behalf of and working with its 200 odd member institutions, has been active in efforts to overcome this limitation. These range from expansion and reduction in the cost of bandwidth available to African knowledge institutions, to strengthening the management and leadership capabilities of those institutions. This paper will explore some of the main issues in this area and the effort to address them.
***Keywords* –** Education, knowledge transfer, development

I. INTRODUCTION

African universities have shared fully in the substantial ferment to which the world of higher education has been subject over the past two decades and more. The causes of this ferment lie in transformations in political economy at both the global and local levels, in factors shaping the world of knowledge generation and application more particularly, as well as in specific economic and social demands of the national and local communities in which universities are situated. This account of the challenges facing Africa's universities will, therefore, be approached from the perspective that as they, like others the world over, struggle to reposition themselves in the changing conditions the strategies they adopt must take these multiple transformations fully into account. Thus, a brief review of the relevant global and local factors will set the scene for a survey of some of the key challenges confronting the university sector on the continent, and the approaches adopted for dealing with them. From the years immediately following the attainment of political independence in most African countries, the typically young and small university sector was invested with high national aspirations and supported from public resources. The situation is a good deal more problematic today, with reduced levels of public funding to a hugely expanded and considerably diversified sector, and a questioning of the mission and mandate, the character, and the proper place of the sector and its institutions and their products in society.

II. CHANGE FACTORS

To help us understand the situation, it is necessary to refer to the broad range changes that have conditioned developments, in Africa as elsewhere. The starting points are the fundamental alterations in the key drivers of wealth generation and power relations, caused by the

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transformations in the global political economy and the heightened significance of information and knowledge to production, management and the services throughout the world. The main elements of this change process are the increasing pace of globalization; the "commoditization" of knowledge and the centrality of its generation and application to social and economic development; the increased openness of national borders to flows not only of goods and services but of knowledge and information; the enhanced mobility and expanded market for high-skill labor; and the new organizational forms and delivery modes resulting from the ICT revolution. Against that background, the explosive growth in the stock of global knowledge and the rapid rate of obsolescence have led to a steady shift from the importance of acquiring a particular body of knowledge to developing the skills for acquiring new knowledge and the capacity for using knowledge as a resource in addressing societal needs. These developments have brought demands for new kinds of knowledge, new modes of knowledge production and dissemination, and thus a complete transformation of the environment for knowledge institutions such as universities and other higher education organizations.

The impact of these transformation drivers was heightened in Africa by economic and social changes specific to the continent from the mid-1970s to the 1990s. These include the virtual collapse of many national economies following the secular declines in the terms of international trade against economies dependent on the production and export of primary products; the descent into autocratic military or civilian one-party or military governance systems in many countries; civil wars and wars between neighboring states; and more recently, the scourge of the HIV/AIDS pandemic. Added to the historic handicaps of underdevelopment bequeathed by colonialism, these movements blunted the ability of African countries to take advantage of opportunities offered by the current phase of globalization, while exposing them to all its negative effects. In relation to universities, the relevance of these developments was the general retreat of the state from social provisioning and the severe reductions in the level of real resources available for African higher education, at the very time that the role of knowledge in social development became accentuated. As a result universities, in common with other social institutions, took severe body blows especially in the last quarter of the twentieth century.

Universities, again in common with other social institutions, face yet another set of constraints. These consist of substantial accountability demands placed on them by a variety of internal and external constituents and stakeholders. In the case of universities these range from government, demanding more stringent accounting for resource use and a bigger say in the agenda of universities, to civil society and business groups, donors and external partners, each pushing sectional interests on the universities. Added to all this is the sheer weight of the expanded student population. While the university can ill afford to ignore stakeholder interests and demands, the cumulative pressure of such demands in the last two decades or so has put into very serious jeopardy the minimum levels of university autonomy in the design and execution of its intellectual agenda that has for decades been regarded as a condition for the effective discharge of its mandate. As African universities seek ways to cope with the variety of challenges and still thrive, this crowding of their space is proving a very serious limitation.

The African University in Context

Widespread university education in Africa is essentially a post-colonial phenomenon [1]. Excluding North Africa with its different history, and South Africa with its special circumstances of both history and resource, only 18 out of the 48 countries of sub-Saharan Africa had universities or university colleges before 1960. With the approach of political independence or immediately thereafter, many African countries regarded the establishment of local universities as a major part of the post-colonial national development project [2]. The new universities were to help the new nations build up their capacity to manage and develop their resources, alleviate the poverty of the majority of their people, and close the gap between them and the developed world. In this regard, the establishment of the new universities should be seen in the same light as the various efforts at nation-building, including the setting up of national industrial and commercial undertakings, national airlines and shipping lines, and the whole notion of import-substituting industrialization. The new nations, set on establishing their national sovereignty by laying the basis for independent national self-development, saw the setting up of these national institutions, including universities as crucial measures to that end.

Mandate, mission and levels of support

Universities, with their promise of indigenous knowledge, local production of expertise and of cadres to staff the public services, the professions and industry, and generally give meaning to national sovereignty, not to mention the prestige they brought, were "unambiguously national institutions set up for national purposes". In this Africa was not unique, as the history of the land-grant universities in the United States of America, as well as university development in Japan of the 1880s and the Soviet Union in the last century indicate. Again, it is no accident that most of the universities of Latin America were set up directly after independence. The objective of all these new institutions was much the same and it is this context that Africa is now faced with bridging the Digital Divide and continuing to serve the public interest by providing home-grown leadership in areas in need of rapid material and social development. Like other national development initiatives, the African university were invariably an explicitly public undertaking financed and supported from public sources. Again, this was not unique to university education. Direct state involvement in the health and education sectors, and the range of state enterprises in agriculture, industry, banking and other services all reflected the need of newly-independent African countries for rapid movement on all social and economic fronts and the contemporary orthodoxy of development economics that assigned to the state a decisive leadership role in these areas.

What were perhaps special in the African situation were the degree of specificity and narrowness in which the purposes were stated in some instances and the generosity of the public support to the new universities. Thus, Universidade Eduardo Mondlane (UEM) of Mozambique was nationalized in 1980 by the new revolutionary government and given the task of producing human resources for the new socialist economy; while the University of Brazzaville from its inception in 1971 had the mission of training national executives within the spirit of scientific socialism. More generally, one of the functions assigned to the University of Ghana was that of promoting African unity.

Today the globalization paradigm and the speed of its development mandate a critical revision of curriculum to adapt while continuing the challenges of existing societal demands. Globalization represents a second wave, the first being the post colonial period when there was an urgent need for persons capable of running the state machinery, the professions and business. Also urgently needed were persons and systems for continuing and expanding the research support services provided to agriculture, health, etc., under the colonial administration. Such was the development ambition, the extent of the need, and the levels of optimism at the time that no expense was spared in supporting the universities and other institutions which were expected to provide the means for elaborating and implementing the national social and economic development project.

In relation to person-power production to replace colonial officials and professionals, Africa's universities are acknowledged to have performed beyond expectation. Even in respect of research and policy support, the record was not all bleak, though it fell short of the very high expectations.

A UNESCO Economic Commission for Africa Conference of university leaders and outside participants held in Tananarive, Madagascar in 1962 speaks to earlier aspirations. The consensus at the conference saw universities as a "key instrument for national development", giving rise to the notion of the "developmental university". At a later workshop organized in Accra in 1972 by the Association of African Universities (AAU), itself conceived at the Tananarive conference, the African university leaders and policy makers who dominated the event sought to give meaning to the workshop theme, "Creating the African University: Emerging issues in the 1970s". They agreed on the need to have African university problems defined and solutions proposed and implemented by Africans, to give the universities a truly "African identity". In their criticism of the colonial hangover and continued dominance by outsiders they were not acknowledging failure, but rather affirming a will to be more proactive and self-directed in response to new demands, and in full confidence that it was doable. Expectations remained high but no higher than the levels of optimism and confidence in the future. Except for those who lived through the experience, it is difficult to capture the purposefulness and positive atmosphere of those years. Yet within a decade of the Accra Workshop, the acceleration of major developments at the global, continental and national levels were to destabilize the environment of higher education in Africa and erode the basis of this early optimism, and the general confidence in Africa's universities, in common with other public institutions. As further background to the current challenges, we now set out briefly the major changes relevant to our account.

The environment changes – globalization and its discontents

The truly revolutionary changes in technology, communications and geo-politics, etc., that have occurred in the last forty years or so, and their impact on all aspects of life throughout the world are well known. Of particular interest for this discussion are their multiple implications for knowledge generation and universities as knowledge centers. What would be useful would be an itemization of some of the key features of the process in order to specify the altered environment and as background to the comments that follow, on some of the challenges that face Africa's universities today. A key feature of economic globalization is the increasingly integrated cross-border organization of economic and financial activity across the globe. This had both policy and technical bases. Against the background of the open international trading system established after the Second World War, the liberalization of exchange controls in the leading industrial countries in the 1970s reinforced by the later deregulation of world money markets, opened up the world market in a way previously unimagined. On the basis of these developments transnational corporations, in their quest for competitive advantage, implemented strategies for worldwide investment, production, sourcing and marketing that have led to a massive dispersal and reintegration of production across the globe. As financiers and speculators took advantage of the possibilities for moving large amounts of short-term money from one jurisdiction to the other instantaneously, this set in train massive flows of trade and finance across national borders, often beyond the sovereign control of states and continues to unify "the world market' in a way never attained before.

At the technical level, spectacular developments in microelectronics, information technology, biotechnology and materials science, and their application to production, management and marketing have revolutionized production in the leading industries of the world. This has also led to a renewed war for natural resources notably from the industrial demands of China and India and as a result placing Africa at the forefront of geopolitical affairs. This environment while in theory should bring about optimism due to the recent increases in the average GDP of African countries is also happening in the face of weak infrastructure and ongoing political crises and skilled manpower shortages.

Concurrent with these global material developments, was also the rise of neo-liberal ideology in the 1980s. The pro-market/anti-state bias of this ideology was both an outcome of the specific form of globalization in the last quarter of the Twentieth Century, and a means for reinforcing those material forces, by pushing for and facilitating the removal of barriers to the flow of private capital in the domestic and international spheres. Coinciding with the radical economic transformations of the former Soviet Union and China and the discrediting of the alternative vision of society by the end of the 1980s, which gave rise to the unchallenged hegemony of capitalism and neo-liberal ideology, which came to be portrayed in many quarters as necessary elements of globalization. Through the conflation of globalization with the neo-liberal agenda and its promotion as the unstoppable movement of our times, a major dose of mythology was introduced into the discourse on globalization – the myth of its inevitability, almost "naturalness". This combination of reality and myth in the globalization discourse continues to have a profound impact on contemporary life and development. The reality of globalization challenges the capacity of the typically marginalized and dependent sub-Saharan African state to generate enough production, savings and investment to ensure sustainable development. For its part, the ideology of neo-liberalism and the institutional arrangements that promote it such as structural adjustment programs (SAPs), limit the policy instrument available to the state for intervening in the market place to ensure the provision of the basic needs of its people, thereby restricting the state's capacity to fulfill its principal function.

The collapse of many national economies in Africa under these forces and the accompanying destabilization of weak social structures throw all institutions, including those of higher education, into a prolonged crisis. The ensuing struggle to survive and find new directions in rapidly deteriorating conditions is within our personal experience. A variety of structural adjustment program (SAPs) were introduced in the 1980s and 1990s to reverse the economic and social crises. The program was intended, first, to give freer reign to market forces by removing rigidities in the production, pricing, and marketing and exchange rate regimes. They also sought to cut back the role of the state, downsizing it and reducing its reach. All this was to be combined with the rapid opening up of the economy to international competition. Whatever the benefits of SAPs – and this is a much-contested issue - they have entailed enormous social costs, including the de-industrialization of national economies and the substantial loss of national control over economic and social policy-making. The results are yet new challenges to Africa's universities - the downgrading of university funding (in favor of basic education) and the pressure on them to adjust to the severe austerity regimen imposed by the various economic stabilization policies, at the same time as they were pressured to increase enrolment and maintain quality levels, without commensurate increases in resources.

The reform effort

While some of the most perceptive analyses of the fundamental structural changes that have occurred in society over the past two decades have come from the universities, they showed little realization of anything like the full implications of those changes for higher education and their own institutions. Thus, until recently, the primary preoccupation of university leadership appeared to have been limited to minimizing the impact of the social changes on their institutions, so they could continue in virtually the same direction and at the same pace, Public subventions, the mainstay of all our universities, could not be sustained at levels that would enable the continuously expanding universities to provide quality teaching, including tutorials, etc. Even less could they be expected to support research, including fieldwork and significant scientific experiments and industrial attachments and, at the same time provide board and lodging for students and municipal services for the university community.

National governments came to this realization earlier than the universities and other higher education institutions in most instances, partly in reaction to the conditionality and policy advice of the international financial and donor agencies in the era of structural adjustment. The typical reaction of governments was to respond to the economic imperative by emphasizing cost cutting and cost-recovery by the universities, while accommodating the political pressure of unmet demand for university places by pushing for increased enrolment. A further factor was the policy of privileging expenditure on basic education at the expense of higher education, a posture reflecting the policy positions of the World Bank and leading donor agencies, and the argument that the social rate of return on investments in basic education was higher than in higher education.

With all this occurring at a time when the under-resourced and run-down universities were having to cope with bloated enrolments, it was not surprising that attempted reforms were met with resistance by the institutions. Clearly, such reforms, challenging long-held assumptions and threatening established interests, were unlikely to be welcome news to the university community. Taking the example of Ghana, Sawyerr [2] noted the manner of introduction of reform resulted in the long-term alienation of important sections of the university community from the Government and its education policies.

The above not withstanding there have been strong indications that the situation is changing, that increasing numbers of university leaders have come round to accepting that what was happening was not simply a disturbance of the normal order of things, calling for little more than measures aimed at restoring the old order. The realization appears to have dawned that many of the assumptions of the preceding three or four decades needed to be fundamentally challenged; that modes of work and organization, as well as expenditure priorities needed to be seriously adjusted.

In what follows, an attempt will be made to identify some of these special challenges, how they are being handled, and what more could be done. It must be acknowledged at the start the impossibility of capturing the full diversity and complexity of the political and economic context and the differential impact on higher education development. Again, given the vastness of the subject, we concentrate on a few aspects only - the patterns and scale of university enrolment, and their relation to new forms of social exclusion; movements in some indirect indicators of quality and the risk of over-extension; and system differentiation and “the public good” dimension of the university function. It is our expectation that comment on this limited set of issues will serve to generate discussion of the general problem of repositioning the universities of Africa for the tasks ahead of them.

III. THE KEY CHALLENGES

The pressure to increase higher education enrolment in Africa reflects three main factors. The first, the historic factor, is the need to fill the substantial unmet demand arising from conditions in the colonial and immediate post-colonial period, when opportunity for local university education was restricted in virtually all African countries. Also important was the specific need to staff the expanded public services, the professions and business in newly independent states. These considerations explain the enrolment explosion in the first years of independence. The second factor is the high rate of population growth, and the consequent youthfulness of the population in virtually all African countries. Large pools of children of school-going age pressed for entry into secondary schools. This prompted the third factor, namely, the very substantial expansion of both primary and secondary education, leading to sustained increases in the pool of secondary school graduates**.** For instance, in 1980, Uganda had 510 government-aided secondary schools, with 37,000 pupils. By 1996, the numbers had risen to 621 and 256,000, respectively. Tanzania experienced a 60% increase in secondary school enrolment between 1990 and 1998, while Burundi is reported to have experienced an explosion in secondary school enrolments

Participation rate

Despite the remarkable expansion of enrolment, the gross enrolment ratio (GRE), that is, the proportion of young people aged 19-24 that is in university, is, on average lower in Africa than anywhere else, and can be considered inadequate for the demands of the modern knowledge economy. While the average GRE for all developing countries went from 5.2% in 1980, to 9.6% in 1996, the corresponding increase was from 1.6% to 3.6% for sub-Saharan Africa. Yet these African averages mask considerable variation from one country to the next. Thus, while the ratio for countries like Burundi, Mozambique and Tanzania fell short of 1% in 1995, others at the high end were – Botswana: 5.3%; Gabon: 8% and South Africa: 18.1% (World Bank 2002: Annex 13). In view of this generally low participation rate, rapid and substantial increases in enrolment at all levels of the educational system can be justified as necessary for the well-being of society and the competitiveness of national economies in the present state of globalization and the centrality of knowledge. There is thus considerable room for further enrolment expansion in order to meet the medium-to-long-term demands of the knowledge society for high-level skills. In the ideal situation, policy in Africa should, in consequence, aim at providing the maximum opportunity for the highest number to participate in higher education. However, under current conditions, a number of limitations need to be noted. First is the absence of the resources required to provide, even at current levels of enrolment, for teaching and research at adequate quality levels, with obvious implications for educational quality generally. The second and related factor consists of stagnant national economies with already limited job openings for most graduates and poor prospects for self-employment. Thus the provision of higher education to the masses would exacerbate an already difficult situation. A third and, in many respects, the most interesting feature, is the fact that the expansion in enrolment has not led to a broadening of the social composition of the student body. To the contrary, all the evidence suggests that in combination with other developments, the pattern of access to university education is introducing novel forms of social exclusion. This will be examined further.

Implications for quality

The first implication of enrolment expansion at this rate and under present resource conditions concerns the issue of quality. Almost without exception, resources failed to match the rate of increase in enrolment. African universities were, therefore, called upon to do more with less in terms of infrastructure, teaching and research facilities and staff. The implications of this for the quality of teaching and research will be examined later.

Quality and Relevance challenges

The principal contribution of a university to society turns on the quality of the knowledge it generates and imparts, the habits of critical thought it institutionalizes and inculcates in its graduates, and the values of openness and democratic governance it promotes and demonstrates. These are essentially subjective phenomena, which pose enormous problems of definition and attribution. For present purposes, the easiest means of getting a handle on the issue of the quality of performance of universities is to use indirect indicators such as:

- the caliber and commitment of the teaching and research staff;
- the range and quality of the curriculum and pedagogy;
- the quality and extent of educational facilities, including the means of accessing traditional as well as worldwide knowledge.

In the colonial and early independence years, the question of the quality of the universities in Africa was hardly ever in issue as the institutions were able to operate at close to “international standards”, in effect, the standards of the relevant colonial power. There were two main reasons for this: (a) the nature and the extent of the relationship that the African institutions and their faculty had with metropolitan institutions helped set and maintain metropolitan standards; and (b) the small sizes of the universities and the relatively substantial resource support from the state meant that they had the resources for doing quality work. To take up the first point, relations between the universities and the metropolis took a variety of forms. From the start, they were modeled after metropolitan examples, and typically started off as colleges or affiliates of metropolitan institutions. For the ex-British colonies, the first post-war universities were set up as colleges “in special relationship” with the University of London. Staff appointments, syllabi and examinations were controlled from London. In any event, as even the local staff had invariably been trained and socialized in the metropolitan institutions, local institutions followed the metropolitan models faithfully. French and Belgian policy had a broadly similar effect. This general situation continued into independence when, often with subsidies from the former colonial powers, metropolitan staff continued in service at these institutions. Again, initially with metropolitan subsidies, faculty and potential faculty of the institutions obtained scholarships and other facilities for general staff upgrading and graduate education at foreign universities. This ensured substantial continuity in the qualifications, values and attitudes of staff as well as the curriculum and pedagogy at the new African universities.

In the British system the external examiner scheme, under which the teaching and examination processes of the new institutions were subjected to oversight by faculty from metropolitan institutions, helped to maintain the standards established during the period of direct tutelage. In addition, collaborative research involving local and expatriate researchers, as well as joint publications in both metropolitan and local journals ensured the maintenance of international standards in research and publication. Though the universities opened up to the wider world after independence, bringing in experience from the United States, the Soviet Union and Eastern Europe, China and Cuba, the British, French and Belgian influence long persisted, especially in what might be called the "first generation" of universities.

The second factor that helped to ensure the quality levels of the institutions was the crucial fact that for many years the institutions remained small with low enrolments and, in addition to substantial state subventions, benefited from support by foreign governments and international donor agencies and foundations. Staff enjoyed reasonably good conditions of service, and there was in place an adequate staff development program which ensured that young faculty moved on to higher qualifications, while senior faculty had leave and other opportunities for self-renewal and updating. All this meant that even after the cessation of direct external tutelage, the autonomous institutions had the staff, the systems, the values, the resources, and the facilities to maintain quite high levels of teaching and scholarship.

The globalization paradigm such as the proposed Knowledge Engine model evaluated by bodies such as the PES builds on the historical model discussed above with the difference being the scale of local knowledge capture potential inherent in integrated regional projects such as the power pool projects of South Africa (SAPP), West Africa (WAPP) and North Africa (NAPP) [3].

Programs such as the Purdue long-term economic model and R&D programs, Electric Power Research Institute's (EPRI) Road Map Initiative & Strategic Science & Technology (SST) [4] remain foundation candidates, from which interdisciplinary synthesis over a wide range of applications can be generated. The information density contained within these sector initiatives provides sufficient 'Synthesizing Capability' for creating knowledge enabling infrastructures. The Purdue study addresses regional and country specific power generation opportunities analyzed over various economic scenarios and different generation types i.e. Hydro, fossil fuel Thermal, natural Gas etc. The EPRI Electricity Technology Road Map Initiative and the Alliance for Global Sustainability (AGC) both have an international focus and represent a major convergence or synthesis of global Industry Experience and R&D. EPRI in particular has over 150 participating electricity stakeholder organizations, The Roadmap seeks to develop a comprehensive vision of opportunities for electricity-related innovation to benefit society and business. The Roadmap also translates that vision into asset of technology development destinations and ultimately the needed R&D pathways. The creation of the Roadmap began with the exploration of opportunities in five distinct topical areas:

- *Sustainable global development*
- *Electricity and economic growth*
- *Power delivery Infrastructure*
- *Power Production*
- *Environmental Knowledge Base*

THE KNOWLEDGE ENGINE ™

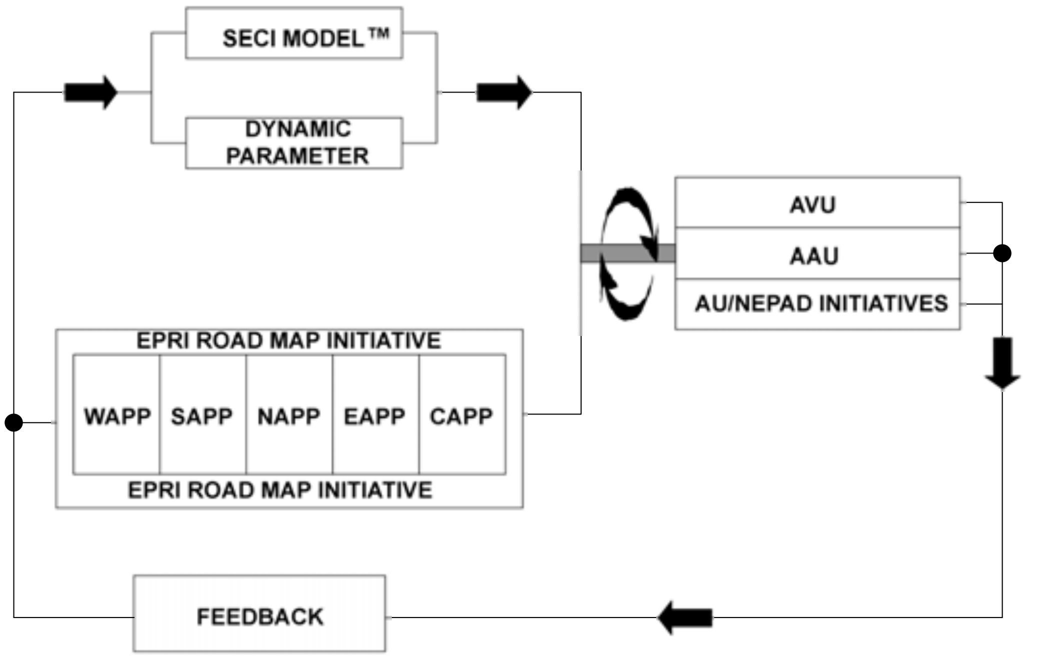

Figure 1 – The Knowledge Engine

As to the curriculum and pedagogy, while these remained basically faithful to the metropolitan models on which they had been based, they were progressively transformed over the years by the infusion of locally relevant perspectives and material. They should be furthered with the ICT tools available for knowledge capture and application.

Infrastructure challenges, Implications: the learning environment

Virtual environments internationally and regionally can provide a matrix of human and material possibilities that can help stem the effects of the Brain Drain and problem of aging scholars. A virtual environment in the true sense of the knowledge economy is not a detachment from local conditions but a ‘knowledge umbrella’ and dynamic organism that can only enhance local conditions across all sectors of society.

This type of enhanced participation locally and international basis should help minimize alterations in the demography of the faculty as the professorship ages which bears not only on the quality of research and teaching, but also on the crucial task of mentoring junior faculty. As is well-known, the development of research skills takes place principally "on the job", i.e., in the course of conducting research, whether as an individual effort or as part of a team. It is in this process that the skills and insights acquired as part of formal training are sharpened and extended. Moreover, on-going research, particularly when it is collective or networked, provides an irreplaceable opportunity for the experience of each member of a team or network to complement and help raise the capacity of others. For young and mid-career researchers such participation, especially under the mentorship of senior colleagues locally, internationally and regionally, constitutes the most effective form of research capacity development. From this perspective, questions of the mentorship of junior faculty and the supervision of graduate study assume the greatest significance for the maintenance of a research culture and proficiency in the academy.

Also the practice of enabling faculty to get away from regular teaching once every seven years, to spend up to one year renewing themselves was one of the most effective means of enabling faculty to remain abreast of developments in their field and maintain international contacts. Once again because this environment becomes a’ living organism’ creating a wide variety of dynamics relationships which will certainly include exchange programs such as working at advanced laboratories with professional colleagues, completing research projects, catching up on the literature or pedagogy. As the crisis at the universities deepened, this ideal picture was decisively fractured.

What about "the public good"…?

As previously noted, the 1980s and early 1990s witnessed a turning away of the state and most external donors from support for the universities, resulting in the under-resourcing and general deterioration noted above. Africa's university leadership and their apex organization, the Association of African Universities (AAU) has consistently argued against this policy of neglect. This can be seen from the declarations at the AAU Harare Meetings of the late 1980s as well as the various statements emanating from the Association advocating much greater attention to Africa's universities. There were also some countries and donor agencies that maintained strong support and advocacy for university education throughout the period. These included the Swedish Agency for Research Co-operation with Developing Countries (now SIDA/SAREC), the governments of the Netherlands and Norway and, for a period, the International Development Research Center (IDRC). Private foundations like the Ford and the Rockefeller Foundations continued to support regional organizations for research and training.

Since the mid-1990s, there has been increasing realization that the policy of neglecting Africa's universities had led down a blind alley. The major turn around appears to have been the World Development Report, 1998, which acknowledged the indispensable role of Africa's universities in the revival of African economies. Much more direct and trenchant support was provided by the Task Force set up by the World Bank and UNESCO, which in its report in 2000, laid out a careful analysis of the contribution of higher education, not only to economic development but also to the general social and cultural development of Africans struggling to keep up with the knowledge society. More recently analysts of the higher education scene in Africa have forcefully argued the case for the "re-insertion of the public good concerns into the agenda of higher education transformation".

As has been previously [2], the determination of the public good and the mode of its advancement through higher education are far from simple. The point of departure is part of a more general ideological position that, consciously or unconsciously, regards "the market" and its logic as the driving forces in social and economic policy. The result is "the privatization of the public sphere", with the diminution of the role of state and community in social and economic and management, and policies of cost-recovery for social services." [3]. Against this background, the emphasis on the social ends of higher education would seem to run counter to general drift of policy. This puts into question the efficacy of mere advocacy for the restoration of the "public good" in higher education, without addressing the roots of the problem in political economy.

It is, therefore, important not to equate advocacy for broader objectives for the reform process with that for the re-insertion of the "public good" in higher education transformation. Since notions of the "public good" turn on particular assumptions about the proper ends of social development and the most effective and just means for attaining them, advocates of the primacy of the market in social and economic affairs can make the case that market efficiency in all areas is the most effective means of generating the resources for creating the conditions of social and economic well-being, and therefore of serving the "public good". The "public good" is not the monopoly of those opposed to the current over-emphasis on the market!

The electrification model as proposed to the AAU for examination made up of the best International R&D has to offer through institutions and the manufacturing merits serious attention. The African regional programs that are at it's core while focused on electricity development and technical in orientation is in effect a benefactor to constituencies with different, sometimes conflicting interests on any number of issues which could effect a balance in the debate on ‘public good’ because of the wide sector participation in it realization.

As higher education provides both social and individual benefits, difficult questions arise about what should be the relative weight of public and private contributions to its maintenance. Put at its simplest, those who favor the primacy of public support argue that higher education is a “public good”, and so, notwithstanding the benefits that individuals necessarily derive from it, it should be a charge on the public purse if it is to achieve the broad range of social purposes that it serves. The other side argues that it is essentially a “private good”, even allowing for the obvious social gains, and so primary responsibility for financing it should lie with the direct beneficiaries. This is an important but old debate, into which we need not enter. Of interest to us are some of the complications that the “public good” position has to negotiate.

It is necessary to distinguish the notion of the public good, as such, from particular conceptions of what it entails in terms of public policy actions and measures in specific social settings a particular time. There are those who consider that that under current conditions, Africa’s best policy is to push for the maximum economic efficiency and value-for-money, on the assumption that the increased productivity and wealth that is generated will ensure the welfare of all. On this view, the higher education policies drawn from the current rightward slant in conventional political economic wisdom - cost-recovery, the orientation of curricula to perceived labor-market demands, and the infusion of the culture of business into university management - are all in the right direction. On the other hand, if the advancement of the “public good” is seen as calling for more than economic efficiency, if it requires, as well, broader social and economic transformation towards a more just and socially coherent society then, clearly, this could not be left solely to “market forces”. It would require more direct emphasis on the development and implementation of policies consistent with the social purposes of higher education, namely, the equalization of the life chances of talented individuals irrespective of their social background and financial capabilities; the generation of knowledge in as wide a variety of fields as possible and the development of different skills and competencies, not just those “needed” by the market today; and the deepening of democracy by producing and making more widely accessible critical social knowledge.

IV. CONCLUSION

The central message of these early assessments is that the idea of the developmental university is not without contradiction and complication. While there is no disputing the propriety of the concern to ensure that universities, like all other social institutions, made their due contribution to social development, there has always remained a question about the tolerable and feasible limits of such involvement, consistent with the basic mission of the university - teaching and research. As noted above, over and above the caliber of its graduates, a university’s contribution to development turns on the quality of the knowledge it generates and disseminates. Thus commentators on the developmental university have pointed out the indispensable role of the quality of its knowledge-generating base as a condition for a university’s effective discharge of its service and development functions. Thus, pushing for service and outreach without dealing with the massive quality deficits in the academic heartland is at best a risky undertaking.

A second risk factor is the danger of a fundamental overload on the universities as they struggle to be all things to all people.

It is against this background that the challenges facing Africa’s universities and their various attempts to survive and thrive must be assessed. In this connection, two points may be made.

(a) It is necessary to emphasize the complexity of the environment within which higher education reform has to be undertaken. To the historic problems that need to be overcome - low participation rates, inequitable access, reduced resources available to both state and institutions, and limited capacity of the state to make its own policy choices – two more have been added, namely, the novel demands of the knowledge society and what I would call, more generally, "the immediacy of the external", that is, the absence of insulation from the direct and immediate impact of global factors, including pressure from powerful transnational commercial interests.

(b) The second and related point is that, there are no easy choices. To say this is not to counsel despair, but to caution the many in government and the donor community who have all-too-often insisted upon one-sided, simplistic, usually economic prescriptions for dealing with these hugely complex problems. The determination of the proper mission and the mandate as well as the operational modes of universities in such a wide variety of historical and material conditions requires very thorough and realistic assessment of history, material circumstances, political/economic conditions and prospects, against the general background of global movements.

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VI. BIOGRAPHY

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5. Towards Developing a New Model for the Pricing of Electrical Energy in Continuously Changing Environments

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Abstract: Historically, the pricing of electrical energy has been supplier driven. In general, the electrical supply industry was promoted as a state owned public company guided by regulated tariffs. The monopoly arrangement served the industry for many decades. Under this model, large-scale electrification has been achieved globally.

With increasing demand for more and more electrical energy from finite primary energy sources, the fundamentals of availability, affordability, quality and security of supply have on many occasions arisen to drive new debate on industry structure, ownership and efficiency. Many calls have been made for a competitive industry structure with the argument that competition will promote the most effective economic utilization of scare primary energy sources and yield the lowest costs to customers.

A certainty is of a continuously changing environment for both suppliers and customers. Following extensive research on the workings of the traditional monopoly model of supply, delivery and consumption and the experiences of many countries to competitive market models, a new approach to market modeling is proposed. Emanating from the physics of electrical energy, we record that once produced, the energy must be consumed. The electron produced is unique and so is the consumption, unique. Thus, a one to one mapping relationship emerges between customer and supplier and the whole process of delivery is customer initiated and driven. The second hypothesis is that all customer loads and supplier generation profiles can be decomposed into unity load/supply factor and less than unity load/supply factor.

When a unity load factor customer is mapped onto a unity supply factor power station (base load power station), a firm relationship independent of time commences between buyer and seller.

Simple bilateral power purchase agreements can define the relationship and the details of delivery can be worked upon. The workings of Eskom South Africa and the setting of the world's lowest cost benchmark for electrical energy are presented as testimony.

In the case of a less than unity load factor customer; many options are available. Many customers can work together and pool their loads and operations so as to create a unity bulk load and apply the same bilateral power purchase agreements as earlier. Auction type platform can be introduced to manage and map less than unity load factor loads with similar pattern supply generators can that have quick start and stop profiles. The workings of the short-term energy market at the Southern African Power Pool are presented as testimony.

A simple new approach provides continuous self awareness and management of energy efficiency and savings, sharing and pooling of complexities and for the direct case of bulk supplies independent of time, the opportunity to employ economies of scale and to minimize generation, transmission and distribution costs. Market power and gaming issues are completely avoided and a longer-term sustainable model is presented for an industry that is independent of structure, ownership and market type.

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1. INTRODUCTION TO THE RESEARCH STUDY

1.1 Idea for the thesis

The proposed area of research is to determine a model for the pricing of electrical energy for a market composed of many buyers and many sellers in continuously changing environments. Many buyers amongst many sellers are the new emerging market environments and a new, original methodology for the pricing of electrical energy is required. For the case of one seller, a monopoly market, this shall be considered as a special case condition in the general model.

Globally, the industry wants to move away from the traditional state owned vertically integrated model of electrical energy generation, transmission and distribution with standard regulated tariffs towards that of a competitive commodity market that promotes market based pricing [1]. The economic argument is that competition will promote a lower cost outcome for customers' [2].

From my work experience, we note that:

a. Standard regulated tariffs in a monopoly market, generally based on cost recovery methods, have th main disadvantage of promoting the total recovery of supplier inefficiencies from the customers revenue.
b. A monopoly industry structure has the advantage of creating large economies of scale such that lower cost outcome is possible by technology and design of appropriate plant and equipment.
c. it is known that customers of electrical energy, suppliers of electrical energy and the regulator of the electrical energy industry are continuously challenged on the pricing of electrical energy. Customers purchase electrical energy as a primary energy source for their value-added activities. With increasing competition, customers are continuously challenged to manage operating costs and improve profitability and sustainability. The general call from customers is choice, value for money, quality of supply, fairness in pricing and transparency in composition of tariffs.
d To protect customer interests, competition is promoted as the best choice to a monopoly environment. The regulatory process is currently being stimulated to promote and support an open competitive environment for electrical energy production and dispatch. Here the price of electrical energy is set by competitive bids between buyers and sellers or between sellers and a reference load forecast as set by the power system operator. The dynamics of moving from a monopoly to a competitive environment is currently being experienced in the numerous models launched at various sites internationally.
e. Suppliers of electrical energy have a similar call in terms of value for money as seen from revenues, cost of sales and profitability. The call for fairness in reflecting and recovering costs for both the quantity and the quality of supply delivered is now increasing. With the introduction of open markets, the obligations traditionally associated with monopolistic structures such as the security of supply and the obligation of supply are also on the agenda for review.
f. The role of the industry regulator gathers momentum with increasing market liberalization. A strategy of minimum interference in an open competitive market is promoted. This strategy is valid provided that the attributes of independence, fairness, transparency, affordability, obligation to supply, obligation to deliver quality of supply and value for money exist. At best, the regulator is also experiencing the challenges of change and is forging a new relationship with the competition commission.

2. BACKGROUND

Society continues to grow totally dependent on electrical energy. Price and quality of supply are the key parameters of continued interest. Clancy [3] concludes that the benefits of using electricity saves time, contributes to improved health and saves money as compared to other energy sources. Electricity is valued because it is very convenient, clean and instantly controllable at the point of use. Pansini [4] notes that people have become so accustomed to flicking a switch and having instant light, heat, action and communication.

With changing customer needs and requirements, the trend is for a move towards an open industry having a market-managed model for the determination of electricity prices. For a general power system, from de la C Chard [5], a typical power system is given in Figure 1. Here three generating stations {G} are interconnected by transmission lines {I} that feed into main transmission lines {M} which feed substations {SS} serving load centers and then onto the distribution system having feeders {F} with further step down substations {S} feeding into reticulation networks {D}.

Grid connection offers convenience, price, reliability and quality of supply to most customers. The one disadvantage is that the use of electricity is not constant over time and the fluctuating consumption has a significant effect on the cost of the supply system.

The unique feature of an electrical power system is that electrical energy cannot easily and conveniently be stored in large quantities but used instantly in the quantities that are needed [6]. At any instant in time, the energy demand must be met by corresponding generation.

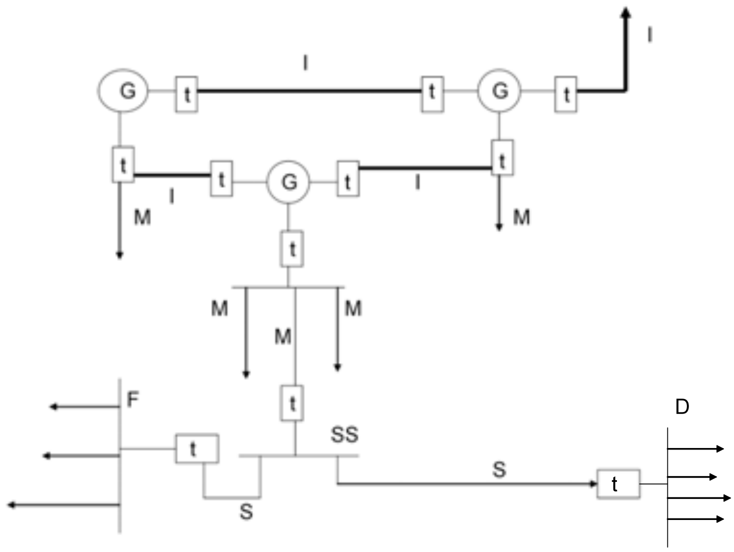

Figure 1: A Typical Power System Layout

The changes in demand of individual consumers may be fast and frequent. However, as one accumulates the consumption from individual consumers, through the distribution network, to the transmission level, the changes in demand become smaller and smoother due to aggregation [6]. Thus at the transmission level or wholesale level, the rapid changes are less noticeable, generally predictable and dependent on seasonal impacts and local weather conditions.

Thus customer time of consumption is critical. At an aggregate level, this translates into a utility problem and various management and pricing strategies are designed and implemented to limit the fluctuation. Further, it is customer consumption that leads production and this is a key attribute for inclusion in the model. Chard [5] records that electricity supply is of the nature of a service where all equipment and personnel must be available for use day or night, awaiting the moment when each particular customer makes his demand on the service. In figure 2, Chard [5] presents a typical load curve for a load center composed of industrial and domestic consumers.

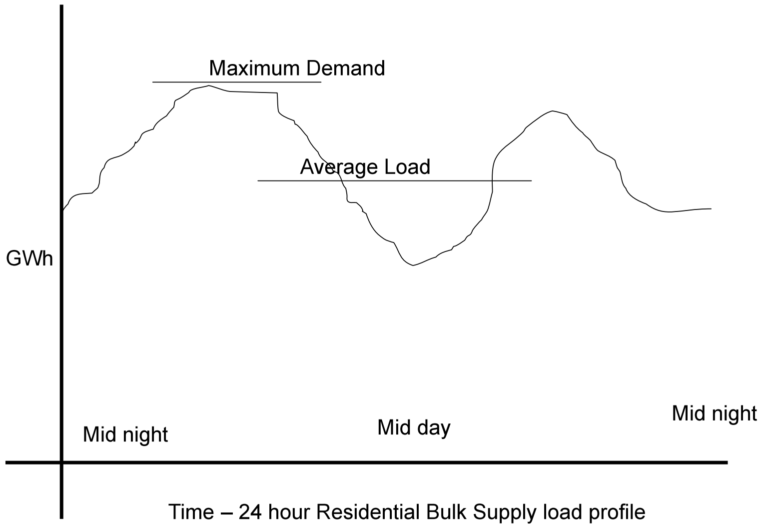

Figure 2: Typical Load Curve for a Bulk Residential Supply

We can define load factor = average load/peak load. It is the energy actually supplied over the 24 hour period, expressed as a per unit of the energy which could have been supplied during the same period had the demand remained constant at the maximum value. The time is the same for both these amounts of energy. Daily time = 24 hours and annual time = 8760 hours (24x365).

The cost of grid electricity to the customer generally involves two components; a fixed connection fee to cover the capital costs of adding the customer to the grid and a tariff for energy consumption. The supplier recovers its investment and operating costs through the price it charges its customers. Tariffs differ from country to country. Examples of tariffs are available on request from any utility.

Commencing with model building, we have the following initial ideas:

a. ***A customer driven model is to be developed whereby the customer sets and defines the consumption schedule……………………..{1}***

This is now the first starting point and refers to the load profile a presented by the customer as shown in figure 2. The load profile can be computed for each and every customer and will be unique to each customer. It can be computed for a group of customers and also have unique features describing the group of customers.

Let us introduce the market as composed of many buyers and many sellers as the general case. Let us also make the assumption that the business environment is open and fair, with transparent transactions and each buyer is free to source electrical energy from the offers of sellers. The goal of all participants is to seek lowest cost positions by promoting economies of scale from technology applications.

b. ***An open market environment having many sellers serving many buyers ………………………{2}***

c. ***A production environment that promotes large economies of scale for the generation of the lowest per unit cost of electrical energy by virtue of the application of technology and appropriate plant and equipment design. ………………………. {3}***

We now add that quality of supply to be a given constant [7] and reduce the focus to just pricing for scheduled quantities. We also accept that the interconnection between the many sellers and the many buyers is infinite as defined in the grid electricity structure of transmission and distribution. This infinite connection also means that buyers are embedded in the distribution process from manufacturing (generation) to consumption (load) and opportunities to switch to other competing energy sources are limited or not practical. Customers are thus wholly embedded in the distribution system of electricity and totally dependent on the continuous supply of electrical energy at the lowest cost. We can thus create a model whereby the buyers and sellers are virtually alongside each other and the area of focus is the pricing of the commodity, electrical energy.

3. NEED FOR RESEARCH IN THIS FIELD

The contribution of the proposed project is to develop a customer driven sustainable model for the pricing of electrical energy. The customer driven model will also be an original, innovative approach as traditionally suppliers have developed the pricing models and strategies from a supplier perspective and not a customer perspective. The old supplier approach can be considered a natural approach for a monopoly structure so as to ensure cost recoveries from a captive customer base. In an open and continuously changing environment, a supplier approach may not be the best approach for modeling.

For the model, it is proposed that a solution be developed that integrates the strengths and opportunities of the monopoly industry structure with the strengths and opportunities of the open competitive industry structure. The solution to be developed should be adaptive in design so as to ensure sustainability given a changing marketplace. My learning's to date shows that each proposed pricing system is unique and is customized for the local operating environment given a defined market status with market rules. The proposed direction of this project will be to build a generalized model based on first and fundamental academic principles and then to test the model for general acceptance under varying operating conditions.

Continuing, to construct the model from the initial ideas, we have:

Customers of electrical energy are totally dependent on electricity as their energy source; they enjoy the instant control at the point of use and their behavior is entrenched to flick a switch and have instant output……….…………….………{4}

Later in the research study, we come across the Californian Experiment of 2000. The above statement has far reaching implications for the Californian Model and is discussed in detail in the paper published from this study.

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4. NEED FOR THIS RESEARCH

In the spring of 2001, I attended and participated in a postgraduate course on managing reform and regulation in the electricity supply industry.

a. The first learning is that the primary focus of regulation is not customer competitiveness. Customers are important but more important are the issue of market power and access for new investors of generation capacity. The design of the various international market models is set on achieving the objectives of reduced market power and open access to all new investors even if the end result is higher electrical energy prices and outages to customers.
b. The second learning is that the new market models have not contributed to any new transmission infrastructure. The existing transmission system was built during the period

of regulated monopoly or on the basis of a supplier-customer bilateral power purchase agreement.

c. The third learning is that the new market models have encouraged peaking type generation plant but not base load type generation plant. Base load investments in general lag. With increasing consumption and demand, electrical energy prices will naturally increase.
d. The fourth learning is that at Eskom, the natural monopoly electricity supplier in South Africa, we must do our job even better; to continue to excel in terms of customer satisfaction, shareholder satisfaction and the overall business results. We must set the global benchmark for service delivery and customer satisfaction. Once this is achieved, any argument for change to a new model will require greater depth of review and a longer term for study and examination. The converse applies equally.
e. The fifth learning is that an in-depth study be conducted of the various market models to determine key elements for success or failure as part of the research for this thesis.
f. The sixth learning is that in all cases, the time to contract forms the foundation for the trade of electrical energy.
g. The seventh learning is that investments are of a long-term nature. The cash flows from customer revenue are substantial and can provide adequate interest cover with schedule debt repayments. Short-term investors are attracted to these cash flows.
h. The eight learning is that whatever the model, the end result of our actions must be sustainable. Prices for electricity delivered must be predictable and competitive.
i. The ninth learning is that customers are the purpose of business. Suppliers exist to serve customers.

My learning from this study clearly shows that a customer driven model for the pricing of electrical energy is absent and needs to be developed. This work must be done in association with the use of the physical power system, the quality of energy delivered and the economies of scale for lower cost energy production

5. THE EMERGING GAP IN KNOWLEDGE

In general, the electricity supply industry is changing in structure from that of a vertically integrated, single owner, regulated monopoly to that of an open competitive market for wholesale suppliers and buyers. For retail customers, the choice of supplier is an emerging option.

But:

All these changes are taking place without any change to the physical power system. The physical power system continues to remain constant in structure and operations as built in the regulated monopoly era. The physical power system continues to serve the existing participants in the market, the new market entrants and accommodates the new regulatory rules. It is simply being stretched. Large-scale blackouts and widespread disturbances are predicted and have already commenced to occur [70].

In this evolving change from a monopoly market model to that of an open competitive market model, several gaps are emerging. Some of these gaps are as follows:

a. there exists uncertainty with respect to the accountability for the obligation to supply
b. similar uncertainty prevails for power system security and for power system strengthening
c. the emerging higher emphasis on short term generation investments
d. the introduction of higher risks for long term generation investments
e. the introduction of unstable and unpredictable future electrical energy prices

Pansini [4] reports that in the last two decades of the twentieth century, there was a distinct decline in the installation of new generation capacity for electric power in the United States. The decline is attributed to several factors such as:

- Decline in nuclear generation due to adverse public opinion and increasing costs emanating from increasing regulations
- The introduction of stringent rules for emissions by the Clean Air Act
- The reluctance of regulated utilities to risk capital expenditures in the face of deregulation and divestiture of generation assets
- The endeavors to meet electric demand through load management, conservation, introduction of renewable energy sources and distributed generation

These gaps are certainly not customer focused and cannot support customer competitiveness in local, regional or global markets. It is contributing to anxiety and loss of confidence. One solution is to scrap the proposed changes to that of an open competitive market for wholesale suppliers and return to the single owner, monopoly structure, a vertically integrated, regulated model. The built in inefficiency is whereby all costs associated with low or poor productivity is collated and passed onto customers for full recovery. The latter could be minimized with incentive-based tariff regulation. On the other hand, most economists would argue that an open competitive market is the longer-term sustainable model for both buyers and sellers.

6. THE RESULTS EMANATING FROM THE RESEARCH STUDY

6.1 Sample Profiles: Discuss Sample and Characteristics

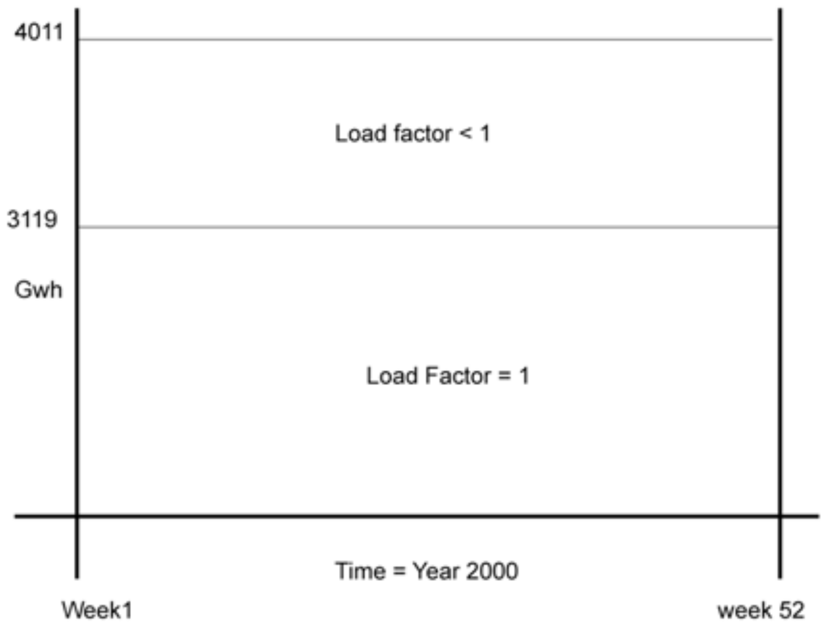
All the data samples were collated from the operating business at random. The random characteristic was selected so as to increase the validity of the conclusions. The data was collected from the South African national grid.

The data consists of a random collection of customers with their load profiles mapped for different time periods. Most of the customers belong to the industrial category. This category is equivalent to that of bulk supplies to municipal loads comprised of domestic, commercial and industrial.

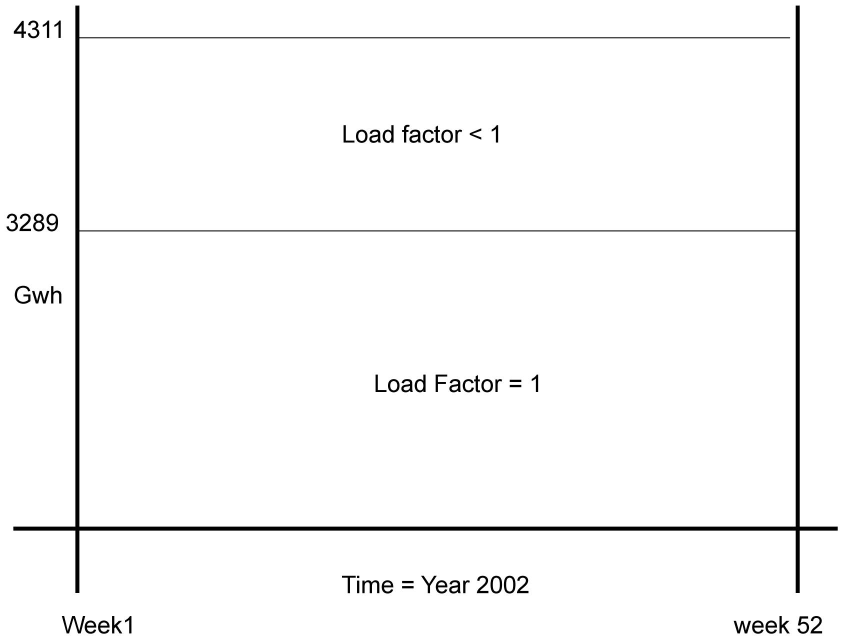
The power station load profiles are also collated. In one day in 2002, the total dispatch schedule is presented for all the power stations that were commissioned for dispatch. The time period is hourly and thus many daily load profiles can be constructed for each of the power stations; for each generating unit of each power station.

6.2 Presentation of Results

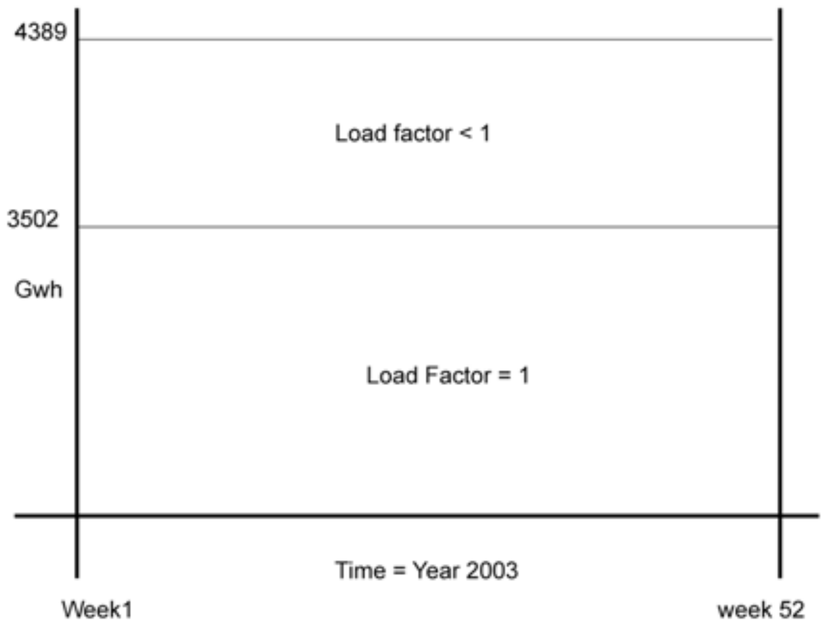
From the given data, we decompose the loads into the categories of loads at unity load factor and loads at less than unity load factor. The results of this decomposition are given in figure 3.



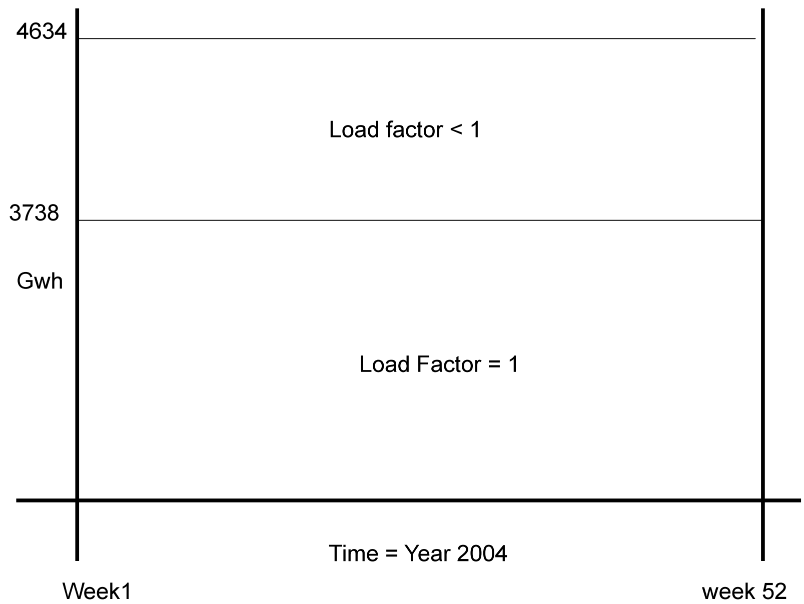
Year 2000: 892 GWh is at a load factor < 1. Ratio of Min/Max GWh sent out = 78%.



Year 2001: 1039 GWh of load is at LF <1. Ratio of Min/Max Energy Sent Out = 76%.



Year 2002: 887 GWh of load is at a LF<1. Ratio of Min to Max GWh sent out = 80%.



Year 2004: 896 GWh of load is at LF < 1. Ratio of min/max GWh sent out = 80%.

Figure 3: Load Profile of Net System Energy Sent Out in South Africa for the Years 2000 to 2004

The overall load factor on the national grid is high. It is more economical to serve unity load factor loads as this represents the case for the most efficient employment of resources. The 20% of load at load factors < 1 is a small part of the total load and represents the size of the market for the power exchange; 900 – 1000 GWh. Analysis of the demand profiles for the same period provides the following capacity at < 1 load factor; 7555 MW for year 2000, 8862 MW for the year 2001, 8172 MW for the year 2002, 6360 MW for the year 2003 and 8353 MW for the year 2004. On average, 8000 MW of capacity is available for the power exchange market.

In a random collection of samples from power system operating records, the load profiles continue to exhibit the same pattern irrespective of weather conditions, time of day, day of week or month of year. The load profiles of seventeen large key customers are analyzed. The customers range from aluminum smelters, to steel plants, to ferrochrome smelters and gold mining operations. The unity load factor profile dominates. In cases of less than unity load factor, then the variable portion is small and equivalent to that seen at the national level; some 20% variability. The Mining and Industrial Category dominate the South African load. The key customer accounts are large and the customers are ready to commence trading for the variable portions.

At the supplier end, we have the view from the power stations. This is very much a mirror view as seen from the customer end. Based on the hourly load forecast, power stations are contracted for delivery. A random collection of the daily contracts is provided showing the packing against the hourly load forecast. On the same set of schedules, the reserve capacity is also shown. On closure, a full dispatch schedule is provided for all power stations; for each generating unit at the power station. Once again, the load profile pattern matches the patterns as provided earlier.

6.3 Discussion of Results with respect to the hypothesis: statistical analysis, interpretation of results; discuss limitations of study; draw the conclusion on the confirmation or refutation of the research hypothesis

The results presented shows clearly that the hypothesis proposed could be developed into a working model for application in any environment irrespective of industry structure or limitations. This non-dependence on electricity supply industry structure is a key finding and adds to the strength of the model when developed from a customer perspective. Further, we can even have the case of a mixed supply environment whereby old state owned power stations could find a space for their continued operations whilst the private sector can be invited to provide for new and growing capacities. Both old state owned and new privately owned power stations can operate side by side with equal pride and total independence of each other. This is because each has a mapped unique customer and revenue flows are defined and assured.

The results presented are valid for the case when we add power delivery and energy management back into the customer – supplier relationship. Both power delivery (cost of transmission, distribution, reticulation and power losses) and energy management (ancillary services such as regulation, balancing and provision of system reserves) can be added costs to the cost of energy as determined by the wholesale market pricing and the power exchange pricing. The cost reflective packaging of tariffs also has strength in that customers can easily evaluate value received and has the choice of switching to alternative energy sources.

The model has no limitations and continuously opens new business opportunities for the benefit of the greater economy. It goes beyond the benefits of a monopoly model or a competitive market model and provides an integrated approach to the long-term sustainability for sourcing and securing energy supplies. There is no regulatory obligation to supply, just a free and fair market for business transactions.

6.4 Expected impact of results: Discussion of results with respect to externalities and sensitivities

The random selection of data showed that the model is insensitive to weather conditions and environmental effects. Once set, the customer driven consumption is based on production parameters and output is fixed. Passing changes in weather or environmental effects are generally ignored. However, for the case of seasonal variations, the variable loads have great room for movement and generally peak for the case of heating in winter and air conditioning in summer; posting equivalent peaks for both summer and winter. However, once step shifted into the prevailing season, the behavior remains constant and unaffected by small variations or changes in weather patterns. The seasonal impact is predictable and can be accommodated in the long range load forecasting.

6.5 Highlights

The model totally ignores electricity supply industry structure and market structure. This is a fundamental strength given that the chapter of services is generally made complex by social and political processes. In this innovative and new approach, the world is seen through the eyes of the customer. The customer is the purpose of business and at this late stage of the industry development we now return to the first basics; the customer is the purpose of business. The overshadow was cast by supplier driven monopoly modeling of the industry; political driven agenda's that protected state owned monopolies, and economies of scale arguments that promoted lower costs and prices once all pooled into one.

Another concluding highlight is the simplicity of the model in structure and operations. The simplicity contributes to enormous strength of the model and will support the testing and validity under varying operating conditions.

7. IMPLICATIONS FOR FUTURE STUDY

The proposed model is new, innovative, creative and simple in structure and operations. A typical power system consisting of a diversity of customers and power supply options should be prepared as a board game; similar to monopoly and played infinitely. During play, one could encounter issues or constraints for further analysis. However, in all the trial model operations, none were encountered; again reflecting on the simplicity of the model. The use of electrical energy is not limiting. This model can be extended to other services such as water and gas.

8. CONCLUSION

When variability is removed from the obligation to supply, we have a constant output in terms of a power system structure and operations. Our study has shown that up to 80% of the power system is constant and it should be managed accordingly. The key fundamentals here are affordability, continuity of supply and security of supply.

For the variable parts of the business, appropriate variable models and custom designed plant and equipment should be made available. This 20% or minor market component can also be appropriately designed and operated.

Then finally, when external environmental effects disturb the set market operations, contingencies can be planned and prepared for. Normal spinning and stand by reserves can be procured for the "what if" condition. Customer load interpretability can also be pre-planned. The smart outcome is no rough and widespread bang-bang control for customer load shedding but defined outcomes for mapped customers to come off when allocated generator has faulted or is unavailable. The options are endless and customer and supplier joint workings can table more creative solutions.

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BIOGRAPHY

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6. Preserving Low Cost Electricity while Improving the Riverine Environment: A Case Study of Ghana's Akosombo Dam Complex

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Abstract - This paper presents the strategy for development of a stochastic programming model of the operation and capacity additions to a large hydro/thermal electricity generation complex. The proposed model minimizes the incremental costs of operating the complex so as to return river flows to pre-dam patterns. It will focus on a representative year made up of wet and dry seasons far enough into the future to allow adjustment of thermal and hydro generating capacities and the initial level of the reservoir, but not the capacity of the reservoir itself. The model will be run first to find the operating and investment strategies which minimize electricity costs, and then run so as to minimize cost subject to equating seasonal reservoir inflows to seasonal outflows – so called "Run of River, ROR" operation. Using data from Ghana's Akosombo/Kpong complex, likely outcomes of the model are presented and compared, based on existing capacities of the system.

Keywords **–** Hydrothermal scheduling, run-of-river, Africa, Akosombo, sustainability.

1. INTRODUCTION

Current thinking among those concerned with the deteriorating health of aquatic ecosystems associated with hydro-electric dam caused alterations in natural river flows is to consider returning these flows to pre-dam patterns [1], [15]. Such an alteration would involve operating dams as run-of-the-river (ROR) facilities, adjusting turbine outflows to equal inflows into the reservoir, rather than operating the turbines so as to minimize the operating and construction cost of generating electricity, or for flood control purposes. This concept is hardly a new idea; there are over 900,000 Google citations related to restoring stream flows to their pre-dam patterns, and as of 1995, there had been 15 experiments either proposed or occurred in the U.S. alone to test the concept [1].

What would be the electricity cost penalty associated with such changes in reservoir management, and what strategies might be used to minimize this additional cost? Again, this is hardly a new question. Several [2] articles have appeared which address this issue, most dealing with the short run (capacity fixed) costs of ROR operation.

While the answer to that question will vary depending on circumstances, the generic structure of the cost increases, and the actions that can be taken to minimize the increases, can be identified by means of a simple model of the operation of a mixed thermal-hydroelectric system.

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Figure 1. Location of the Akosombo Dam

The purpose of the model is to attempt to answer the question of how to minimize short term and long term increases in operating and capacity costs caused by ROR operation, using a stochastic programming model of a representative year's wet and dry season operation of an existing hydro dam complex.

The year is chosen far enough in the future to allow the capacity of the hydro and thermal generating units, the transmission lines, and the opening water level in the reservoir to be adjusted, but not the capacity of the reservoir itself. The model will be applied to Ghana and the operation of the Akosombo/Kpong complex in that country (Figure 1).

The model will first be run assuming the goal is to minimize electricity costs over the planning horizon, with water accumulated during the wet season stored for dry season use. The same model would then be run with the added constraint that seasonal inflows must equal seasonal outflows. This ROR operating assumption – which means opening seasonal water inventory must equal ending seasonal inventory – will increase costs, since ROR operation can result in spillage, shifts to more expensive fuel purchases, or both. It is expected these incremental cost values, and the actions that can be taken to minimize these additional costs, will depend primarily upon:

(a) The ability of the existing hydro units to handle the peak water inflows during the wet season without spillage, and the existence of profitable markets for the sale of any surplus wet season electricity;
(b) The ability of the thermal units to satisfy a larger fraction of demands during the dry season, or the existence of less expensive electricity purchase options during the dry season.
(c) The degree to which reservoir inflows are concentrated in the wet season.

If neither the hydro system, the thermal system, or the markets have these abilities, and inflows are concentrated in the wet season, then the switch to ROR operation will either involve substantial additional construction and operating costs, or, if generation additions are not possible, spillage during the wet season and unmet demand during the dry season. Both alternatives have the potential to substantially increase the cost of electricity.

2. PROPOSED MODELING

The model would minimize the operating and annualized levelized new investment costs of meeting demand in a representative year, consisting of two seasons, wet and dry. This year is far enough away in time to allow for the construction of needed additional thermal units, the addition of hydro generation capacity to existing dam structures, and the readjustment of the water levels in the reservoir, but not time enough to adjust the working capacity of the reservoir. Access is assumed to markets for the forward purchase of gas for the thermal units, spot sale and purchase of gas, and spot purchase and sale of electricity.

The economic trade-off options available to minimize the incremental costs of ROR operation would be:

(1) Gradually relaxing the ROR constraint to identify the levels of relaxation that result in substantial reductions in ROR incremental cost.
(2) Choosing to import electricity in the open market, rather than build a new plant and produce the shortfall, thus avoiding the fixed cost of a capacity expansion.
(3) Choosing to spill water rather than build additional water turbines, with the decision again depending on the capacity shortfall.
(4) Choosing the normal operating level of the reservoir so as to optimally trade off the forgone electricity revenue caused by the filling of the reservoir against the increase in water turbine input per unit of output (ft3/MWh) associated with the higher heads resulting from higher reservoir heights.
(5) The possibility of managing a group of reservoirs with differing water inflow patterns to take advantage of this inflow diversity to minimize ROR incremental costs.

The model would have three stochastic elements:

(a) The forward price of fuel for the thermal plants at the beginning of the representative year;
(b) Growth in demand in the region (both known prior to the beginning of the representative year, but after the investment decisions); and
(c) The weather conditions during each of the two seasons- wet and dry- in the representative year, known only as the representative year progresses.

Thermal unit fuel prices would have three scenarios; (a) a low gas price scenario; (b) a "business as usual" gas price scenario, which assumes prices remain at current levels; (c) a high price gas scenario, which assumes gas prices rise to higher than current levels.

Demand growth also has three scenarios:

(a) The high rates of growth projected by electricity grid planners in many countries, which usually assume the success of government sponsored electrification programs.
(b) Growth rates based on long-term historical electricity use.
(c) Lower than expected growth rates, which assume the failure of government sponsored electrification programs, and little economic growth.

Weather conditions for the wet and dry seasons are known only as the seasons in the representative year progress. These conditions determine water inflows, electricity demands, and spot fuel and electricity prices during these wet and dry seasons. Five weather scenarios are possible for each of the seasons, with differing probabilities, water inflows, and demands; (a) a relatively rare flood scenario; (b) a wetter than normal scenario; (c) a normal scenario; (d) a drier than normal scenario, and (e) a relatively rare drought scenario. For sustainability, the opening water volume at the beginning of the representative year wet season must equal the expected value of the ending volume a year later at the end of the dry season. Also specified are the capacities of the existing hydro and thermal units, the unit MW sizes of additional thermal and hydro units which can be added, the number of hydro units that can be retrofitted into the existing dam structure, and the existing transmission capacity of the lines connecting the region to its neighbors and options for its expansion, which act as a constraint on the amount of electricity that can be imported and exported. The initial level of the reservoir at the time of planning the expansion of capacity is also known.

In addition to the costs of the various activities, three relationships will govern the model's behavior. First, (a) the water balance equation, which requires for all scenarios that the ending water volume equal to the opening volume plus inflows minus discharge through the turbines minus any spillage which takes place. Next, (b) the electricity demand/supply balance equation, which requires for all scenarios that demand be met by either thermal generation, hydro generation, distributed generation, purchase or sale of electricity on the spot market, or if all else fails, unmet demand (i.e., rolling blackouts, etc.).

Finally, (c) the water turbine input per unit of output factor, measured in ft3/MWh, relates the volume of water retained in the reservoir to the number of cubic feet of water flowing through the turbines necessary to produce a MWh of electricity. The cubic feet required to produce an MWh provides the link between the water balance equation and the electricity balance equation. The relation is the product of two functions. The first relates input per unit of output to the head of the reservoir, using a simple relationship derived from first principles [16]. The second relates head to the volume in a reservoir, which, as one might expect, is a highly non-linear relationship that depends on the contours of the specific reservoir. The combination of these two functions results in the turbine input per unit of output factor being a non-linear function of the reservoir volume. In the model, average water volume will be the average of two of the decision variables in the model, the volume of water in the reservoir at the beginning of the representative year, and the water inventory at the end of the wet season of the representative year. The turbine input per unit of output factor will enter the water balance equation described in (a) above as a conversion factor, converting the MWh generated by the hydro units, a decision variable, into the ft3 of water withdrawn from the reservoir during generation. The result is the water balance equation becomes a quadratic constraint, since it contains products of decision variables. While this complicates the computation of the least cost solution to the problem, it does not make the problem unsolvable.

The fundamental investment decision the model would make prior to the start of the representative year is to determine the level of investments in new generating facilities and initial stored water in the reservoir that will minimize the cost of electricity production over the representative year. This calculation will trade off the annualized investment costs of the new generation equipment and the annualized costs of the electricity sale revenues forgone by increasing the volume of water stored in the reservoir, against the operating cost reductions during the representative year allowed by such investments.

The fundamental operating decision the model would make during the representative year is the amount of water to accumulate in the reservoir during the wet season for use in the dry season. Too much water storage means reduced hydro generation during the wet season, which means high thermal generation expenses during the wet season. Too much water storage also runs the risk of reservoir spillage and the waste of "free" electricity, in the case of a scenario with very high inflows. Too little water storage means high thermal generation operating and new construction costs in the dry season, particularly if a drought scenario occurs.

3. GHANA DEMONSTRATION DATA

Representative data were obtained from the West African Power Pool ECOWAS Data Base [13] and other sources ([3-12]) regarding the demand and supply of electricity provided by hydro and thermal facilities in Ghana. As the model discussion has pointed out, a major factor in the additional cost of switching to ROR operation is the degree to which reservoir water inflows are concentrated in the wet months, thus requiring water to be accumulated in the reservoir during the wet season for use during the dry season. Indeed, if there were no such concentration, the costs of switching to ROR would be minimal.

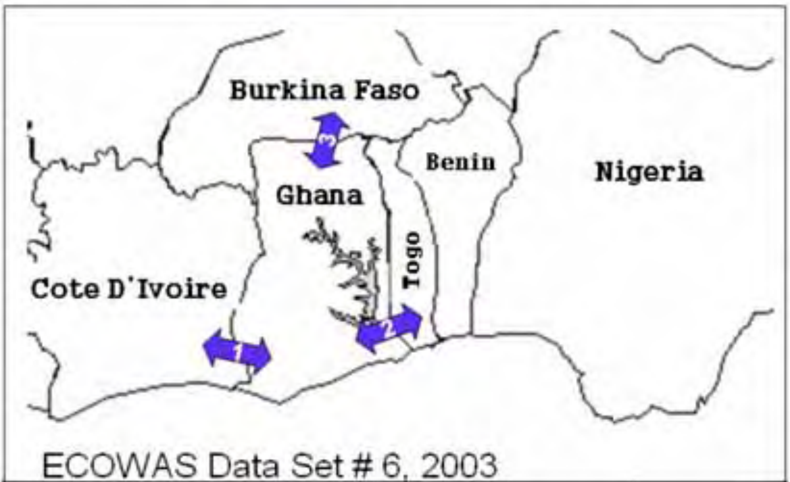
Several sources ([8], [11]) were found which indicated that over 90% of Lake Volta inflows take place during the wet season from May to October. Certainly it can be concluded that inflows are concentrated in the wet season, but the exact amount of the concentration needs to be confirmed with data. Fortunately, the stochastic nature of the model used in the proposed optimization will allow us to explicitly incorporate uncertainty regarding inflow concentration. This will be accomplished by the model's ability to specify the probabilities of the various deviations from the expected "normal" relationship between wet and dry season inflows.

3.1 Hydro Facilities and Input per Unit of Output Factors

Ghana has two hydro facilities, one at Akosombo which forms Lake Volta and has a capacity of 1020 MW [3], and the other downstream at Kpong, a run of river facility running on the discharge of the dam with an installed capacity of 148 MW [4]. While no additional Akosombo retrofit generation capacity is contemplated after the completion of the Akosombo upgrade, which increased generating capacity from 912 MW to the present 1020 MW, the demonstration model will allow such an expansion at costs estimated from previous retrofits of the Akosombo facility [13]. The two existing generator sets are assumed to be out of service for maintenance 4% of the time [13], which means their yearly generating capacity is theoretically 8.578 and 1.244 10^6 MWh/year respectively, if the water is there for generation.

The capacity of the lake is 148 10^{12} liters, or 5.22 10^{12} ft^3 [3], with a maximum operating level of 278 feet [3], although the dam was operating at below 235 feet, [14] near the record low level of 234 feet [14]. While the choice of the level of the lake is, within the bounds of the operating levels allowed, part of the optimization problem, this choice will not be as important as it might seem. The reason is that for sustainability purposes, the model requires that the expected value of the ending water inventory must equal the opening value. Consequently, the major role the initial inventory plays in the optimization is to define when spillage takes place - that is, when inflows plus the opening inventory minus turbine discharge exceed the capacity of the reservoir- and to help determine the head of the dam, which determines the efficiency of the turbines. These operating attributes are to be traded off against the annualized electricity income lost by filling up the reservoir to its determined level.

If one takes into account normal water availability during the year, the yearly generating capacities for Akosombo and Kpong are reduced to 5.1 10^6MWh and 1.0 10^6MWh respectively, well below the 8.5 10^6MWh and 1.244 10^6MWh yearly capacities of the generators themselves cited above [4], [6]. The relationship between firm and average power is taken as evidence that the lowest inflows in a year are about 80% of normal inflows. Data in [6] indicate that the 1.0 10^6MWh long-term average capability estimate for Kpong is based on an average flow rate of 1160m3/sec, or 147.6 $10^6 ft^3$/hour. Data in [6] indicate that the Kpong unit normally operates only 77% of the time, which indicates that the 1.0 10^6MWh is generated by a yearly flow of $(147.6\ 10^6)(8{,}760)(0.77) = 996.0\ 10^9 ft^3$. This implies that the normal input per unit of output factor for the Kpong facility is $996\ 10^9/1.0\ 10^6 = 996.0\ 10^3 ft^3$/MWh, and $996.0\ 10^9/5.1\ 10^6 = 196.0\ 10^3\ ft^3$/MWh for Akosombo.



	1 Cote D'Ivoire 225kV	2 Togo 161kV	3 Burkina Faso 132kV
Practical Transfer Power (MW)	250.0	150.0	30.0
Tie Line Capacity (MW)	287.0	256.0	280.0
Maximum MW Expansion (MW)	300.0	300.0	250.0
Line Loss Factor (%)	6.0	7.3	2.0
Forced Outage Rate (%)	1.2	1.0	1.0

Figure 2. International Transmission with Ghana

3.2 Thermal Facilities

In addition, [13] indicates there are two existing dual fuel capable conventional thermal units with a total of 550 MW of installed capacity, one a 220 MW simple cycle unit with a heat rate of 11,970 Btu/kWh, the other a 330 MW combined cycle unit with a heat rate of 7,980 Btu/kWh. The simple cycle unit would have the capacity to produce 1.445 10^6 MWh/year given its 75% availability reported in [13], and the combined cycle unit 2.457 10^6MWh/year, given its 85% availability reported in [13]. New gas fired combined cycle units are planned to take advantage of the new off shore gas pipeline connected to Nigeria. Data source [13] indicates these will be 330 MW units, with a heat rate of 8,000 Btu/ kWh, capable of producing 2.45 10^6MWh of electricity a year with the 85% availability factor contained in [13].

3.3 Ghana's International Transmission

Since the import and export of electricity will be an option in the model, it is necessary to constrain the amounts by the capacity of the transmission lines to carry the electricity. Data in [13] indicate that currently, the practical transfer capacity of the two transmission lines joining Ghana to the Ivory Coast and Togo is 400 MW (Figure 2), forced outage is estimated at 1%, and line loss is estimated to be 6%, which implies carrying capacity is 3.29 10^6MWh per season.

3.4 Ghana Demand Data

Problems always arise in estimating demand from historical consumption patterns in countries with electricity shortage problems, since use will usually reflect supply constraints as much as inherent demand. In particular, reported wet season use may be higher than dry season use in Ghana simply because reservoirs are at higher levels, and fewer blackouts have taken place in wet than in dry seasons.

Regarding Ghana's current demand statistics, [13] indicates that Ghana's peak demand has been close to 1300 MW and yearly consumption has been in the range of 9.0 10^6 to 10 10^6MWh in recent years, and growing at a rate of around 0.50 10^6MWh/year, which is taken as the normal historical growth rate for the three demand growth scenarios considered in the analysis. Data in [13] indicate that wet season average monthly peak (MW) demand (May-Oct) of 990 MW is 10% higher than dry season (Nov-May) monthly peak demand of 900 MW. Assuming total demand of 10 10^6MWh for the year, normal wet season demand would then be 5.328 10^6MWh, and normal dry season demand would be 4.761 10^6MWh.

3.5 Wet and Dry Season Inflows

The model assumes the wet and dry seasons are of equal 6-month length - the wet season lasting from May to October, the dry season from November to May [5]. As has been mentioned, [8] and [11] indicate that 90% of the inflow takes place in the wet season, and 10% in the dry.

Regarding the year-to-year variation in inflows [9] contains estimates of Lake Volta average yearly inflows, rainfall on the lake, evaporation, and dam discharge from 1961 to 1990. Mean inflow for the 28 year period is 33.0 km^3/year (1,165.0 10^9ft^3), and mean dam discharge 28.4 km^3/year (994.0 10^9ft^3), a number remarkably close to the estimate of 985.0 10^9ft^3/year obtained by scaling up the normal flow out of the Kpong reservoir of 1160.0 m^3/sec [6] per year (assumed to be the normal discharge from the Akosombo dam), assuming a 77% utilization rate from [6] above. Some difference in runoff and discharge is to be expected, even in the case where there is no change in the lake storage level, since the water balance in this case requires that runoff plus rainfall on the lake minus evaporation equal discharge. Historically, evaporation, which has averaged 10.2 km^3/year, has exceeded rainfall on the lake, which has averaged 7.9 km^3/year. As a result, runoff has averaged 8.5% higher than discharge over the period 1961-1990 [5, 9, 10].

The result of all this is that in a normal year, it will be assumed that the yearly water available for management, either by the cost minimization or the ROR rules, is 994.0 10^9ft^3. All departures from normal for the various scenarios for both the cost minimization and ROR modes of operation will use this number as a starting point. To avoid confusion with inflows, the term "water available for management" will be used to describe the 994.0 10^9ft^3 figure, and its variants. Using the 90/10% split assumption and the 994.0 10^9ft^3 starting point, this means that 894 10^9ft^3 of water would normally be available for management each year during the wet season, and 99.4 10^9ft^3 in the dry season.

4. THE RANGE OF FEASIBLE WATER STORAGE OUTCOMES

Given the current thermal and hydro system capacities, what is the range of optimal water storage volumes at the end of the wet season that we would expect to arise from the application of the model to the operation of the Akosombo complex under the normal inflow conditions described above?

4.1 CASE A - Water Storage Allowed

First, consider the range of possible storage outcomes if it was assumed that water could be stored in the wet season for use in the dry, and demand was to be met. The maximum and minimum limits on water storage volume under these conditions can be derived in the following manner.

It develops that the minimum amount stored is set by the maximum water flow possible through the turbines during the wet season. From above, demand in a normal wet season is assumed to be 5.33 10^6MWh, and 4.76 10^6MWh in a normal dry season. Existing thermal and hydro capacities are assumed to be 1.95 10^6MWh [(1.445 + 2. 457)/2] and 4.91 10^6MWh [(8.578 + 1.244)/2] for a total of 6.86 10^6MWh respectively for both seasons, so generating capacity is not the constraint, if the water is there. The normal wet season water inflow of 894.0 10^9ft^{3,} when combined with the 196.0 10^3ft^3/MWh and 996.0 10^3 ft^3/MWh input per unit of output factors allows 5.46 10^6MWh to be generated in the wet season from Akosombo (4.56 10^6) and Kpong (898.0 10^6), and 0.606 10^6MWh in the dry from Akosombo (0.507 10^6) and Kpong (0.99 10^6) apparently meeting demand. Unfortunately, the Akosombo units cannot take that much water, since the 4.56 10^6MWh exceeds Akosombo's seasonal generating capacity of 4.289 10^6MWh, so the capacity constrained hydro system can only provide 4.91 10^6MWh, 4.289 from Akosombo and 0.620 10^6MWh from Kpong. Thus wet season demand of 5.33 10^6MWh will be met by 4.91 10^6MWh from hydro, and the balance of 0.420 10^6MWh from the thermal plants. The water remaining in the reservoir because of the limit on Akosombo generating capacity is 53.0 10^9ft^3, the difference in the inflow of 894.0 10^9ft^3 minus the water used by Akosombo when operating at capacity - 4.289 10^6MWh times the 196.0 10^3ft^3 used per MWh, or 841.0 10^9ft^3.

Regarding dry season demand, this minimum storage strategy, allowing as it does only 53 10^9ft^3 of water to be stored in the wet season for use in the dry season, will utilize that water to generate 0.323 10^6MWh in the dry season. Dry season demand is 4.76 10^6MWh, to be satisfied by 1.95 10^6 thermal supply, 0.612 10^6MWh from dry season inflows, and 0.323 10^6MWh from stored water from the wet season, leaving a deficit of 4.76 - 1.95 - 0.612 - 0.323 = 1.88 10^6MWh, to be made up by some combination of construction of a new thermal facility which would add 1.229 10^6MWh for the dry season, but cost $42 million plus operating costs, purchase the electricity on the spot market, or other options.

What is the maximum amount of water that can be stored, and still meet demand in the wet season? Since wet season demand of 5.33 10^6MWh must be met, the maximum amount is constrained by the capacity of the thermal units to meet wet season demand. From above, existing wet season thermal capacity is 1.95 10^6MWh, which means 3.38 10^6MWh must be met by the hydro units, which translates into using 554.0 10^9ft^3 of water to generate 2.82 10^6MWh from Akosombo and 0.554 10^6MWh from Kpong. Since inflows are 849 10^6ft^3, this means at most 894 – 554 = 340.0 10^9ft^3 can be stored for use in the dry season. This volume, plus normal dry season inflows of 99.0 10^9ft^3, allows 439.0 10^9ft^3 of water to be used to generate electricity, which translates into 2.23 10^6MWh at Akosombo, and 0.44 10^6MWh at Kpong. Total dry season generating capability is then 2.23 + 0.44 + 1.95 = 4.62 10^6MWh. Since total dry season demand is only 4.76 10^6MWh, the deficit is only 0.14 10^6MWh, which can be made up by the purchase of electricity on the spot market, rather than the construction of a new generating unit.

To conclude, the feasible water storage amounts in the wet season for use in the dry range from a maximum of 340.0 10^9ft^3 of water, set by the maximum thermal capacity in the wet season, to a minimum of 53.0 10^9ft^3 set by the maximum volume the hydro units can pass through the units. Determining what is the least cost method of satisfying these demands within this wide range of possibilities is, of course, the reason the optimization model is needed. This normal scenario analysis just gives the broad outlines of the strategy.

4.2 *CASE B - No Water Storage Allowed*

Use of the ROR rule will require additional Akosombo hydro units to be built for wet season utilization, or some means of allowing spillage from the dam, if discharge from the dam is to be equal to the volume of water available for management. This follows from the fact that current hydro unit seasonal inflow capacity of 841.0 $10^9 ft^3$ is insufficient to allow full use of the 894.0 $10^9 ft^3$ available for management during a normal wet season.

For this analysis, it will be assumed that the 53.0 $10^9 ft^3$ of excess water is somehow spilled to maintain the dam discharge at the 926.0 $10^9 ft^3$ level. This means the spilled water is not available for use during the dry season, which means the generation deficit in the dry season is going to be substantially larger than in the cost minimization case. Total dry season demand of 4.761 10^6MWh could be met by the 0.612 10^6MWh of hydro available from dry season inflows, plus the 1.95 10^6MWh available from existing thermal units, leaving a deficit of 2.2 10^6MWh to be made up by the thermal units. The seasonal capacity of an additional combined cycle unit is 1.229 10^6MWh; so additional supply must be found, either from the construction of two such units, the purchase of electricity on the open market, or from other sources. Again, the job of the optimization model is to try and minimize these additional costs. For instance, it may be cheaper for ROR operation to purchase additional electricity on the open market than to build one, or both, of the thermal units, all this to be determined using the optimization model.

5 CONCLUSIONS

The conclusion of the two previous sections is that the switch to ROR operation appears to require additional hydro capacity or spillage to allow wet season hydro water use to equal wet season inflows, and the construction of substantial additional thermal capacity for use during the dry season to meet demand. The task of the optimization is to reduce this additional cost by seeking out cheaper options and selective relaxations of the ROR rules which are cost effective.

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7. BIOGRAPHIES

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7. Strategies and Status of Grid-connection Technology Development in the New Energy and Industrial Technology Development Organization (NEDO)

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Abstract-- This paper provides an overview of strategies and the results of grid-connection-related demonstrative projects of the New Energy and Industrial Technology Development Organization (NEDO). NEDO is Japan's largest public R&D management organization for promoting the development of advanced industrial, environmental, new energy and energy conservation technologies. One of the important objectives of NEDO's R&D is solving problems that arise when distributed and renewable resources are connected to power grids. These issues arise because the power output from most renewable energy resources fluctuates with weather conditions and connecting them to traditional power grids may create power quality issues. The authors introduce grid-connection-related national projects promoted by NEDO in which several energy storage technologies are applied to resolve those issues.
Index Terms-- renewable energy, power system, transmission system, distribution system, power quality, energy storage

1. INTRODUCTION

From the perspective of addressing climate change issues, promoting renewable energy as part of a long-term energy supply strategy is essential. As a result, the use of renewable energy resources is rapidly increasing in electric power systems worldwide. In parallel with this, however, several related issues have also arisen. To address such problems, there is a strong need for research and development efforts in renewable energy applications and the connection of those resources to conventional power grids.

The New Energy and Industrial Technology Development Organization (NEDO) is a publicly funded Japanese organization that promotes the development of new energy and industrial technology. As part of this, NEDO has recently been focusing on issues that arise when renewable and distributed generation systems are connected to grids. In this paper, the authors introduce NEDO's grid-connection-related demonstrative projects and focus on R&D strategies and the results of applying energy storage technologies.

2. GRID-CONNECTION PROJECT STRATEGIES

2.1 Frequency control and balancing issues

The power output from some renewable energy systems, such as photovoltaic systems and wind turbines, fluctuates depending on weather conditions. When large amounts of fluctuating renewable energy are introduced to a power system, the stability of the power system's frequency can be impacted. Because of this, there is concern that a widespread introduction of wind turbines may make it difficult to maintain system frequencies within operational standards. Concerns over frequency fluctuations have led some Japanese utilities to announce limitations on the amount of wind-generated power they will permit within their grid systems. The Ministry of Economy, Trade and Industry (METI) began holding sub-committee meetings in April 2004 to discuss wind power connection issues. Under this sub-committee, study teams analyzed the characteristics of wind power fluctuations as well as appropriate technical countermeasures. Prior to this, in 2003, NEDO commenced a "Wind Power Stabilization Technology Development Project."

Because PV systems produce power in the daytime, when power demand is high, supply and demand balancing is not as serious for PV as it is for wind power, which may produce power during off-peak demand periods, such as at night. However, it is foreseeable that problems in balancing supply and demand could arise if PV systems were to be installed on a widespread basis. In response, NEDO, in FY2006, commenced the "Verification of Grid Stabilization with Large-scale PV Power Generation Systems." In this project, output from large-scale PV power plants will be leveled through the use of batteries.

These projects were designed to identify methods to reduce the negative impacts renewable energy may have on power balancing and the stabilization of frequencies.

2.2 Localized voltage-related issues

There is a possibility that output fluctuations from renewable energy could disturb power quality on localized grids. For example, changes in output from distributed generation systems may cause fluctuations in voltages near the connection point. If distributed generation systems are connected to power grids on a widespread basis, this type of voltage problem could become significant, potentially making it difficult to keep voltage levels within operational standards.

In two demonstration projects related to PV systems, the Verification of Grid Stabilization with Large-scale PV Power Generation Systems and the "Demonstrative Project on Grid-interconnection of Clustered Photovoltaic Power Generation Systems," testing is underway to manage voltage by use of a battery system. In the first project, a PV system was connected to a transmission system and in the second project PV systems were connected to a distribution system. In both cases, battery systems played an important role in maintaining voltage levels within an acceptable range.

2.3 Other issues

NEDO is also studying other grid-connection issues and conducting demonstration projects involving studies of micro grid technologies. In these projects, the focus is on balancing demand with power supplied by renewable energy resources for small utility systems connected to large utility power systems. It was shown that the small utility grids could, at times, be operated independently of the larger utility grids. In these projects, battery systems were one of the key technologies that enable micro grid operation.

Also, technology to prevent islanding is being developed. In the Demonstrative Project on Grid-interconnection of Clustered Photovoltaic Power Generation Systems, a new islanding detection method was developed. NEDO is now planning to support certification of this protection method.

Shown in Figure 1 are several past and present NEDO demonstration and technology development projects. Four of these projects will be completed in fiscal year 2007 and final reports for those projects will be published in the middle of fiscal year 2008.

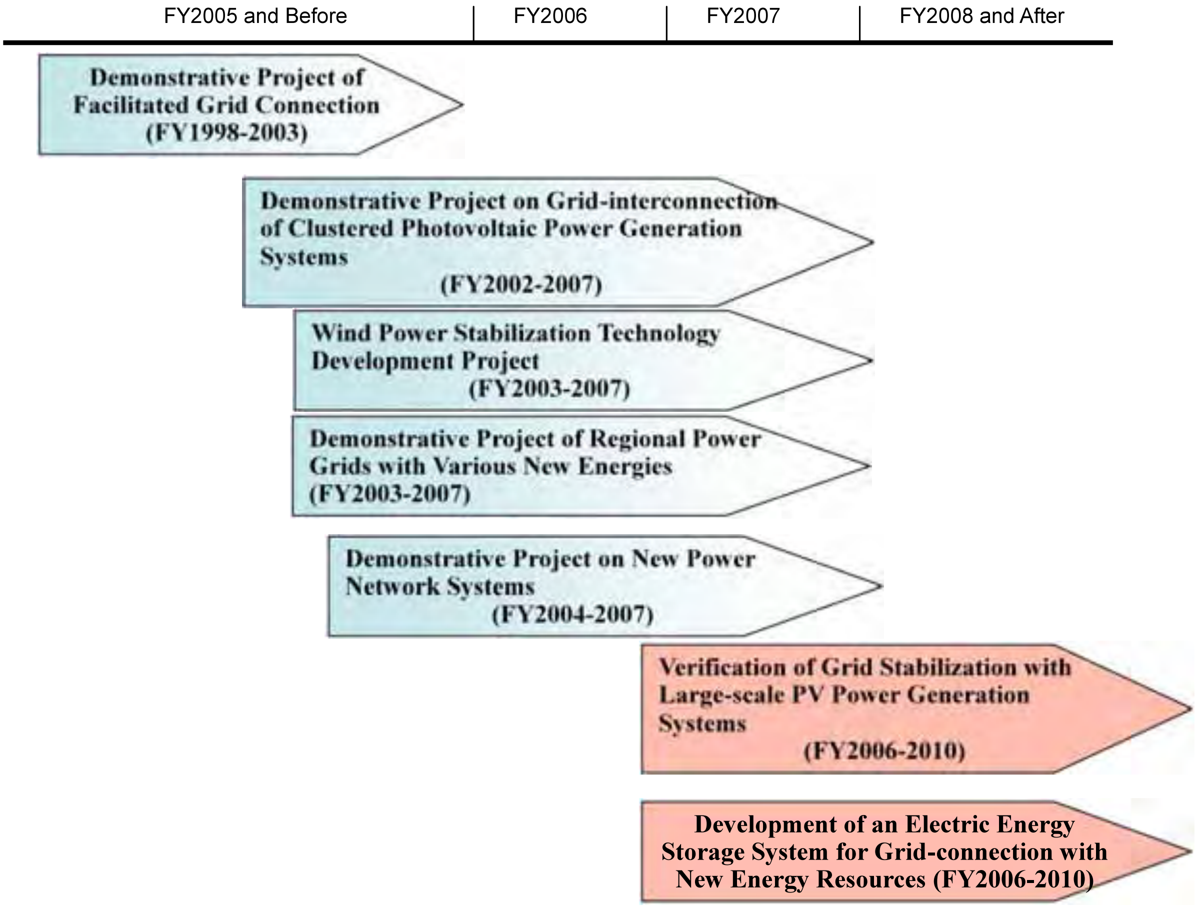

Fig. 1. NEDO's grid-connection projects

3. WIND POWER STABILIZATION PROJECT

3.1 Project overview

The Wind Power Stabilization Technology Development Project (FY2003-2007) was undertaken to demonstrate battery systems that can reduce fluctuating output from wind farms.

The concept, as illustrated in Figure 2, is to reduce output fluctuations from a large-scale wind farm. For this purpose, a redox flow battery system (6MW–6MWh) has been installed at the Tomamae Winvilla Wind Park in Hokkaido. At the demonstration site, several methods for cost effective operation were examined, as was the reliability of the battery system, in order to reduce short-term wind power fluctuations. Also, data on actual wind power output was collected at the facilities of Nikaho-Kogen, Green Power Kuzumaki, Tahara-Rinkai, Aso-Nishihara and Nagasaki-Shikamati for the purpose of simulating the potential benefits of introducing the same battery system at these facilities.

In addition, a wind power generation forecasting method based on weather forecasts was developed and analyzed for the purpose of forecasting the output from wind farms and utility areas over the short and long-term, using actual data collected from other wind farms since fiscal year 2005.

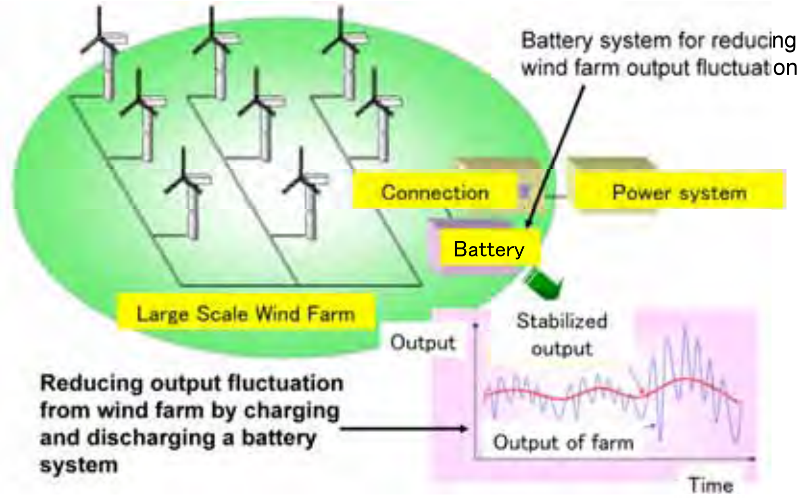

Fig. 2. Concept being demonstrated in the project

Fig. 3. Battery storage building (6MW-6MWh)

Fig. 4. Battery storage tanks

3.2 Project status

Throughout the course of this five-year project, several operating methods were examined at the Tomamae demonstration site. Primary among these was employing first order lag feedback control with the battery system to reduce fluctuating output from the 30.6MW wind farm. Under this control method, several time constants were tested to determine the relation between the time constants and the required battery capacity. Also, a comparative simulation using actual output data from other wind farms, allowed us to determine the required battery size. This information will be useful for developers who intend to use battery systems with new wind farms. Also, several methods for effectively managing batteries were evaluated. Identifying optimum operating modes are important to keeping efficiency levels high, to ensuring a long battery life and to managing the SOC of the battery system.

An important subject of the wind power generation forecasting sub-project is reducing the mean absolute error in consideration of Japanese topography and climatic conditions. In this sub-project, actual output was measured at several wind power farms. The data was analyzed and, along with weather data, was used to create and test several forecasting models. Through the process of developing a forecasting method, a baseline forecasting system was created. NEDO is planning to make this baseline forecasting system public to help utilities and wind farm operators understand how to forecast wind power and to make it easy to later develop their own forecasting methods.

4. LARGE-SCALE PV POWER GENERATION SYSTEMS

4.1 Project overview

In autumn, 2006, NEDO kicked-off a new project called Verification of Grid Stabilization with Large-scale PV Power Generation Systems (FY2006-2010). In this project, a 5MW-class PV power plant in Wakkanai City, Hokkaido and a 2MW-class PV power plant in Hokuto City, Yamanashi Prefecture, are being built to test several technologies for connecting mega solar power plants to a utility transmission system. In the Wakkanai sub-project, a battery system and other technology to reduce voltage fluctuations caused by the output of a mega PV power plant will be demonstrated through the system illustrated in Figure 5. Also, an inverter system that compensates for over-voltage and suppresses harmonics will be developed and demonstrated. The two project sites have unique solar irradiation conditions; Wakkanai City is Japan’s northernmost city, and, as such, the variance in daylight hours is greater than anywhere else in Japan, whereas Hokuto City receives more solar irradiation throughout the year than any other city in Japan. By the end of fiscal year 2007, 2MW of PV will have been installed in Wakkanai City, and 0.6MW will have been installed in Hokuto city. If the projects proceed on schedule, Japan’s first MW-class PV power plants will be completed next year.

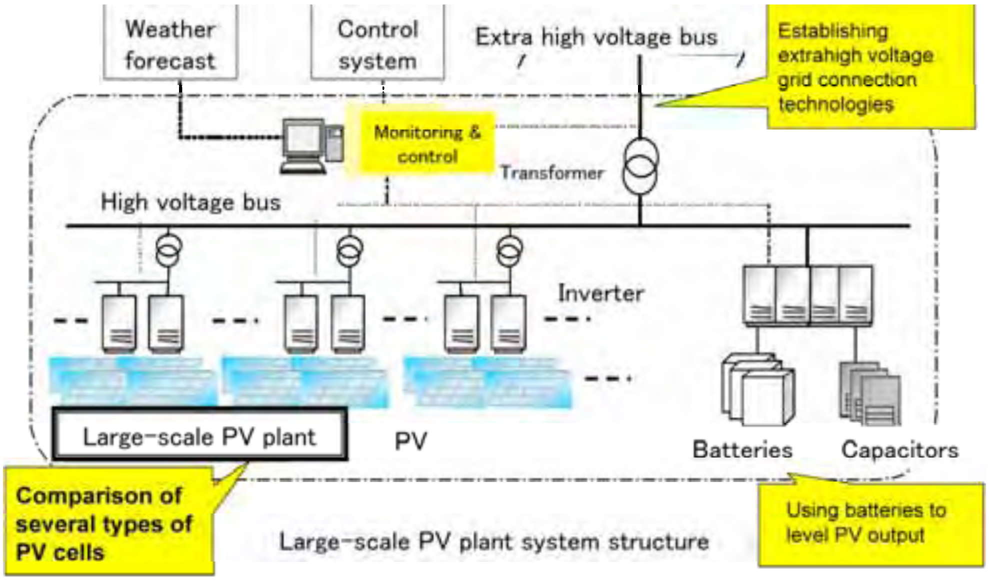

Fig. 5. Illustration of large-scale PV power generation system

Fig. 6. Image of Wakkanai PV power generation system

Fig.7. Image of Hokuto PV power generation system

Fig. 8. Construction of battery storage building (500kW-3.5MWh)

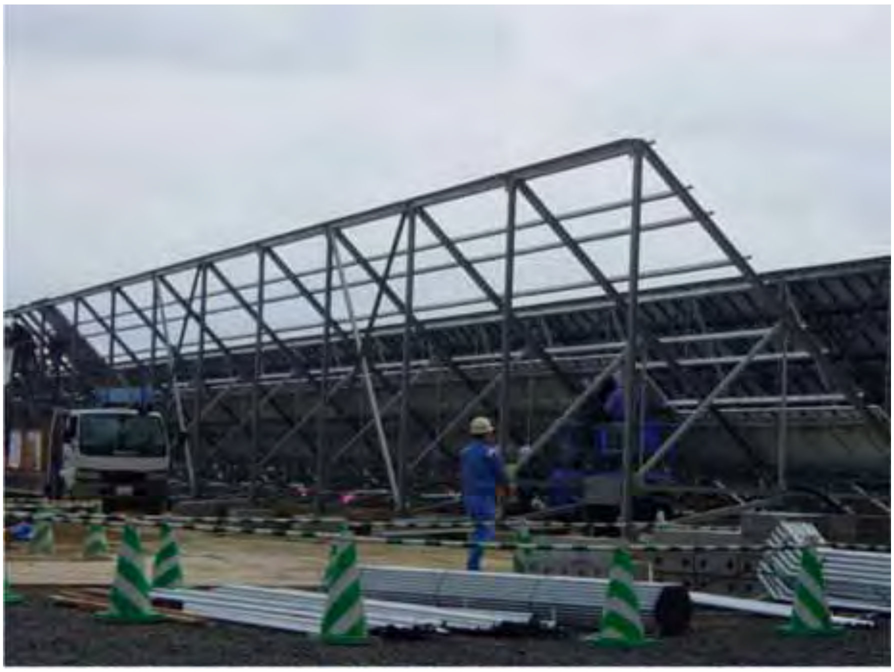

Fig. 9. Installation of PV panels in Wakkanai

4.2 Project status

Fiscal year 2008 will be the third year of the project and the end of this fiscal year will have installed most of the PV panels and related facilities. At the halfway stage of the project, several things have been learned through simulations.

For example, sodium-sulfur batteries have enough output capacity to compensate for PV system output fluctuations. In addition, the batteries' discharge rate can keep pace with the speed of large-scale PV system output fluctuations. We also learned that although the original plan for the Wakkanai site called for the introduction of double-layer capacitors, there are, in fact, very few cases when the capacitors are required.

In the Hokuto sub-project, a reactive power compensating inverter system is being developed. This inverter technology and battery application will help stabilize voltage levels on lines connected to fragile rural power systems.

5. CLUSTERED PV PROJECT

5.1 Project overview

In the Demonstrative Project on Grid-interconnection of Clustered Photovoltaic Power Generation Systems (FY2002-2007), more than 550 residential PV power generation systems were installed in Ota City, Gunma Prefecture, and technologies related to voltage control and islanding prevention on the distribution network were demonstrated.

The main purposes of this project were to develop: technology to counter PV system output restrictions, functions to prevent unintentional islanding, and applied simulation technologies.

In order to avoid PV system output restrictions, an external storage box, housing an inverter, battery and monitoring equipment, was installed with each PV system. When power output from the PV systems caused voltage levels on the distribution line to exceed the maximum nominal voltage level, the excess power was used to charge the batteries, thereby maintaining line voltage within the nominal operational range (101±6V, 202±20V).

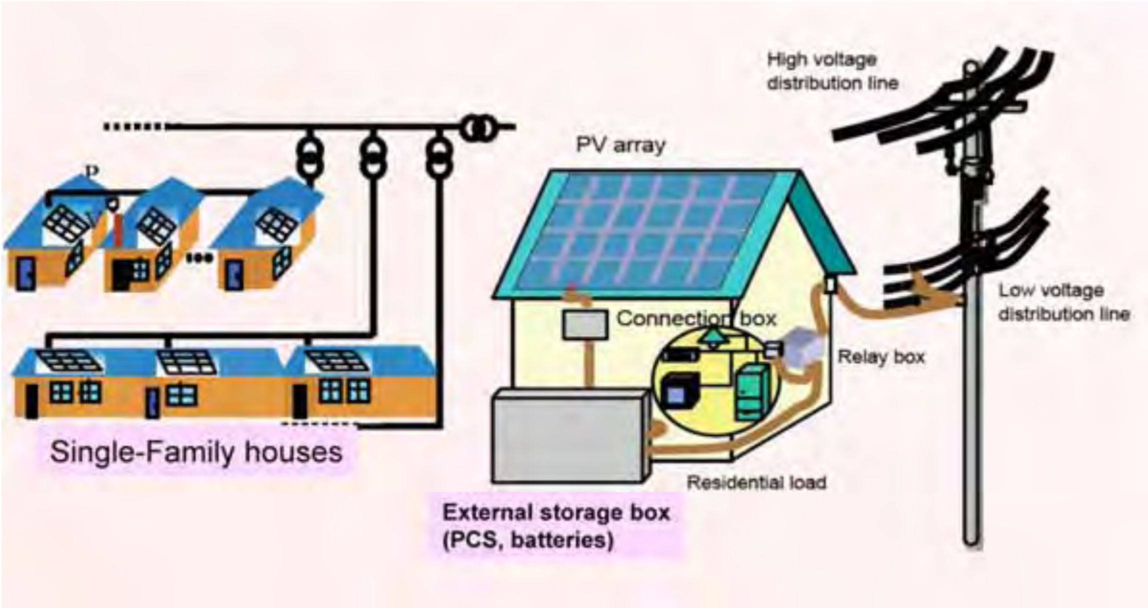

Fig. 10. Illustration of systems installed in Ota project

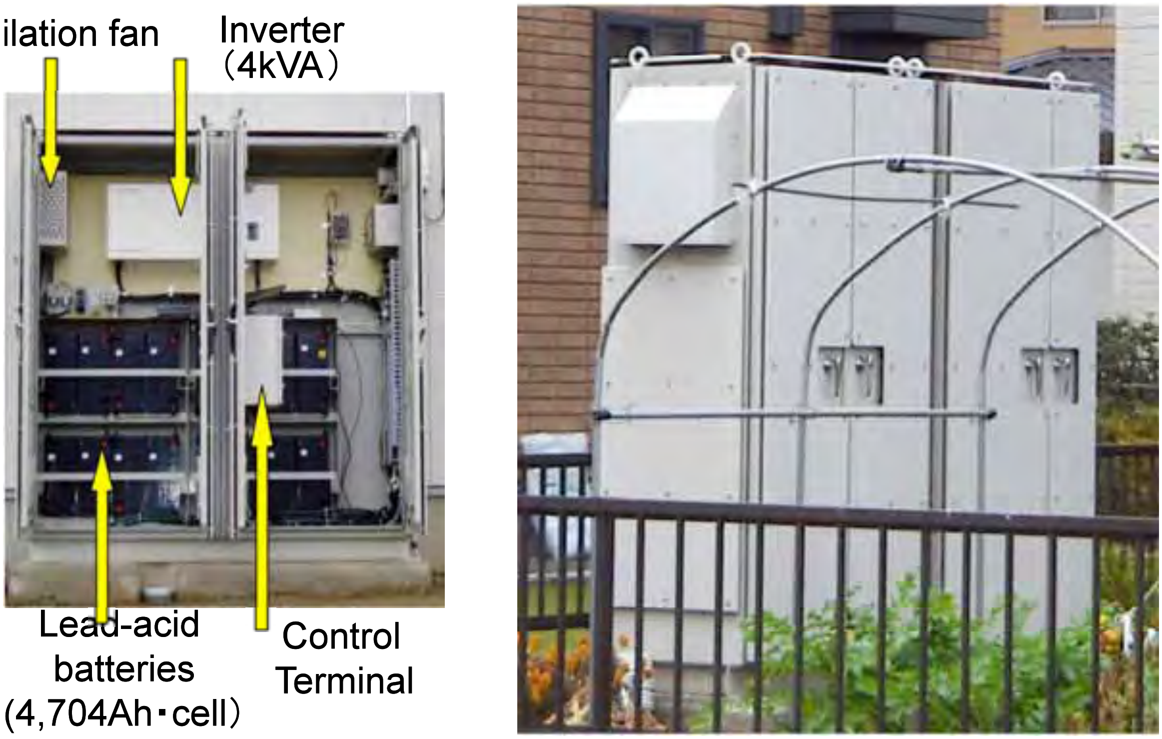

Fig. 11. Inside of external storage box

Fig. 12. Ota City “New Town” area

Fig. 13. Islanding prevention test facility in Maebashi

A PV system must disconnect from the power grid in the event of service interruptions to prevent islanding. However, interference among the equipment used to prevent islanding can occur when many PV systems are installed on the same feeder line. To avoid this problem, a new type of equipment needed to be developed and verified through demonstration testing.

5.2 Project status

A method based on synchronizing reactive power signals to avoid islanding for clustered PV systems was developed in this project. The newly developed islanding detection method was tested at a test facility in Maebashi City. Field test equipment was subsequently installed at the demonstration site in Ota City. In the last fiscal year of the project, proven equipment replaced field test equipment, and additional testing was conducted. In fiscal year 2008, NEDO will start a new project to support the establishment of a private certification system related to clustered PV systems. This kind of effort is thought to be important to facilitate the future dissemination of PV systems.

Throughout this project, valuable operating data measured at one-second intervals was collected. We plan to process that data and make it available to researchers who want to analyze the actual operation of clustered PV systems. Also, simulation methods are being designed and developed to aid in the planning of other clustered grid-connected PV systems and to allow for precise evaluations of the data obtained in this project.

6. OTHER PROJECTS

The "Demonstrative Project of Regional Power Grids with Various New Energies" is one of the most notable projects in the history of NEDO, and it included the three following sub-projects:

1) Demonstrative Project of Regional Power Grids with Various New Energies at Expo 2005 Aichi and Central Japan Airport City (Aichi Project)
2) Kyoto Eco-Energy Project (Kyotango Project)
3) Regional Power Grid with Renewable Energy Resources; A Demonstrative Project in Hachinohe City (Hachinohe Project)

Fig. 14. Aichi project, Rinku-Tokoname site

In the "Demonstrative Project on New Power Network Systems," energy storage and voltage compensating application technologies were developed. In fiscal year 2006, NEDO commenced "Development of an Electric Energy Storage System for Grid-connection with New Energy Resources," another technology development project related to energy storage systems.

Fig. 15. Sendai project, compensating facilities site

7. CONCLUSION

Partially as a result of NEDO's demonstration projects, technologies for reducing the adverse influence of output fluctuations inherent to renewable energy resources used for power systems are now being established. In particular, the importance of energy storage technologies for reducing output fluctuations from renewable energy and for balancing electricity supply and demand has been clarified and addressed. However, we have also recognized new challenges, which are described below:

7.1 Development needs for battery technology

Of course, lowering the price of new energy technology is the most important. However, the cost of technologies related to grid-connection needs to be reduced. For example, as a result of NEDO's research, it has been reported that the price of an energy storage system needs to be halved relative to the existing cost of the cheapest Sodium-Sulfur battery.

In the NEDO project Development of an Electric Energy Storage System for Grid-connection with New Energy Resources (FY2006-2010), a new type of energy storage system will be developed using advanced technologies. In this project, reducing costs by one-half, doubling the life expectancy, and developing safe energy storage technologies are the final targets to be attained over the next 25 years.

7.2 Importance of creating a roadmap

NEDO's experience has demonstrated that attaining a balance between policy objectives and economic feasibility is important for the development of new technologies. The policy contributions that renewable energy can make in terms of protecting the global environment must be the primary driver for promoting the projects mentioned above. However, to disseminate grid-connection technologies, it is necessary to identify markets where such technologies can easily be introduced. This means that small niche markets with high marginal costs must be identified. To undertake such market research, a roadmap for relevant technologies should be created. In so doing, a technology development direction will become apparent and the likelihood of achieving success will increase.

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BIOGRAPHIES

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Nobuyoshi Inoue was born in Hiroshima, Japan, on June 12, 1967. He received his B.E. in 1992, an M.E. in 1994, and a Ph. D. in Engineering in 2003 from Kyushu University. He joined the Chugoku Electric Power Co., Inc. in 1994. From 1998-2001, he was dispatched to the International Superconductivity Technology Center, where he was engaged in research on high-temperature super conducting thin films for electronic devices. In 2007, he was dispatched to NEDO, where he has been working in the management of large-scale PV system projects. He is a member of the Japan Society of Applied Physics.

Yasuyuki Arashiro was born in Itoman City, Okinawa Prefecture, Japan, on September 30, 1975. He received his Master's Degree in Electrical and Electronics Engineering from the University of Ryukyu Graduate School in 2000. He subsequently joined the Okinawa Electric Company. In March 2006, he was dispatched to NEDO, where he serves as a Project Coordinator for the New Energy Technology Development Department.

Yasushi Chiba was born in Hokkaido, Japan, on January 20, 1964. He graduated from Asahikawa National College of Technology with a degree in Electronical Engineering in 1984. He joined Hokkaido Electric Power Co., Inc., in 1984 and was responsible for the design of distribution systems, maintenance, administrative tasks and a maintenance study. He was dispatched to the New Energy Technology Development Department of NEDO in 2006.

Toshiyasu Iwasaki was born in Kyoto, Japan, on July 14, 1964. He received his Master's Degree in Power Electronics Engineering from the Graduate School of Engineering, Kansai University. He entered Nissin Electric Co., Ltd. in 1990.

At Nissin Electric, he was engaged in the design of a voltage dip compensator. He was dispatched to NEDO's New Energy Technology Development Department in July 2006.

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Invited Discussion

8. The Southern African Electricity Challenges to meet Electricity Demand in the Year 2010 when Hosting the Soccer World Cup

Pat Naidoo, Senior General Manager of Transmission Company, ESKOM, Johannesburg, South Africa
Alison Chikova, SAPP Chief Engineer, SAPP Coordination Centre, Harare, Zimbabwe

Abstract:--The paper will provide an overview of the Southern African Power Pool (SAPP's) experience in the area of planning and developing electricity grid interconnection projects. The main economic and technical benefits that can be gained operating an integrated regional electricity grid will be demonstrated. Special reference on bilateral electricity supply agreements, the transmission wheeling arrangements and short-term electricity market (STEM) in Southern Africa will be analysed. The paper will highlight the history of the development of transmission interconnectors in the region. The geographical locations of existing and new transmission projects will be highlighted.
Keywords**:** Power Pool, transmission wheeling

A detailed background of the SAPP Membership, generation technology mix and the peak demand for each country will be analysed and presented.

The new generation projects to be commissioned will be highlighted including the construction programmes to meet the 2010 electricity challenge. The table 1 below highlights the demand and supply situation in the region. It can be highlighted that 54,684 MW is installed but only 46,494 MW is available in SAPP which leaves 8,190 MW not available. The capacity that is not available is due to a number of reasons namely capacity mothballed, capacity under rehabilitation and capacity that is constrained due to fuel and or hydro constraints. This is highlighted for each country. If all this capacity is brought into service before the year 2010 looking at the electricity demand growth and the new planned generation projects, then SAPP will have adequate generation capacity to meet the 2010 generation capacity requirements. This is subject to the fact that funding is made available to have the identified 8,190 MW to be brought back on line.

SAPP will undertake the following projects:

- ***Rehabilitation and associated infrastructure projects:*** These are currently in progress and most of them are under construction with secured funding. The rehabilitation projects will add a total of 1,472 MW at a total cost of USD 1 billion. Funding has been secured for these projects
- ***Short-term generation projects*****:** These projects are expected to be completed in 2010. Feasibility studies and environmental impact assessments on the projects have been completed. By 2010 a total of 5,961 MW of new generation will be added a cost of approximately US$3.9 billion, over and above the rehabilitation projects. The paper will describe in detail how SAPP will meet the electricity challenges to meet the 2010 soccer electricity requirements.

Table 1: Demand and Supply Situation in SAPP

No.	Country	Utility	Installed Capacity [MW]	Available Capacity [MW] *As at Feb 2008*	Installed minus Available [MW]	2007 Peak Demand [MW]
1	Angola	ENE	1,155	870	285	535
2	Botswana	BPC	132	90	42	496
3	DRC	SNEL	2,442	1,170	1,272	1,075
4	Lesotho	LEC	72	70	2	109
5	Malawi	ESCOM	305	246	59	240
6	Mozambique	EDM	248.5	173.8	75	365
		HCB	2,250	2,075	175	
7	Namibia	NamPower	393	360	33	449
8	South Africa	Eskom	43,061	38,384	4,677	36,513
9	Swaziland	SEB	51	50	1	196
10	Tanzania	TANESCO	897	680	217	653
11	Zambia	ZESCO	1,632	1,200	432	1,468
12	Zimbabwe	ZESA	2,045	1,125	920	1,758
TOTAL SAPP			54,684	46,494	8,190	43,857
Total Interconnected SAPP			52,327	44,698	7,629	42,429

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9. Long Term Power Contracts for Meeting the Electricity Requirements of Southern Africa

Lawrence Musaba, Coordination Centre Manager, Southern African Power Pool (SAPP), Harare, Zimbabwe
Alison Chikova, SAPP Chief Engineer, SAPP Coordination Centre, Harare, Zimbabwe

Abstract:--Electricity trading in the Southern African Development Community (SADC) started as early as the 1960s after the construction of the Kariba Dam along the Zambezi river which is on the border between Zambia and Zimbabwe. The commissioning of new interconnector transmission projects led to more power trading and more bilateral agreements being entered into between different utilities. Special reference on bilateral electricity supply agreements, the transmission wheeling arrangements and short-term electricity market (STEM) in Southern Africa will be analysed. The SADC region has been in a situation of a surplus of capacity since the early 1995. The excess of power led to a lot of long bilateral agreements being entered into between different parties. This paper will highlight some of these bilateral agreements, the current status and duration.
***Keywords*:** Cross Border Trading, Interconnections

1. WHAT IS SAPP

SAPP is a regional body that was formed in 1995 through a Southern African Development Countries (SADC) treaty to optimise the use of available energy resources in the region and support one another during emergencies. The Power Pool, whose Co-ordination Centre is in Harare, comprises of 12 SADC member countries represented by their respective Electric Power Utilities. The SADC region serves 230 million people. Utilities in the SAPP have realised that by working together on power projects, a lot more could be achieved than working as individual utilities. The implementation process is quickened with shared expertise from the region. A number of transmission interconnector projects are under consideration.

2. REGIONAL ENERGY TRADE

Regional electricity cross border trading is governed by fixed co-operative bilateral agreements; generally of a long-term duration. The fixed power purchase agreements provide for the assurance of security of supply but are not flexible to accommodate varying demand profiles and varying prices. Access to the transmission grid should be secured in advance before bilateral contracts are entered into. A transmission wheeling agreement is entered into between the buyers, sellers and wheelers of energy. It is the responsibility of the buyer to secure a wheeling path. Currently the buyer of energy pays for the transmission wheeling charge. This arrangement is currently under review as both the sellers and buyers of energy benefit for the energy transactions. New transmission wheeling arrangements are being discussed in SAPP. This paper will look at these arrangements and the implications to the trading parties. Using the experiences of the SAPP as a case study, the experiences gained will be shared.

In April 2001, the market commenced trading with a few participants in the Short Term Energy Market (STEM). The number of participants grew to eight in 2003. With increasing participants and market confidence, the results show that the model is robust and is a recommended framework for cross border short term electrical energy trading. The short-term energy market; designed to be day ahead, compliments the bilateral market and provides another technique for the pricing of electrical energy. With the addition of real time communications and energy management systems, the spot market for competitive bidding is the next step.

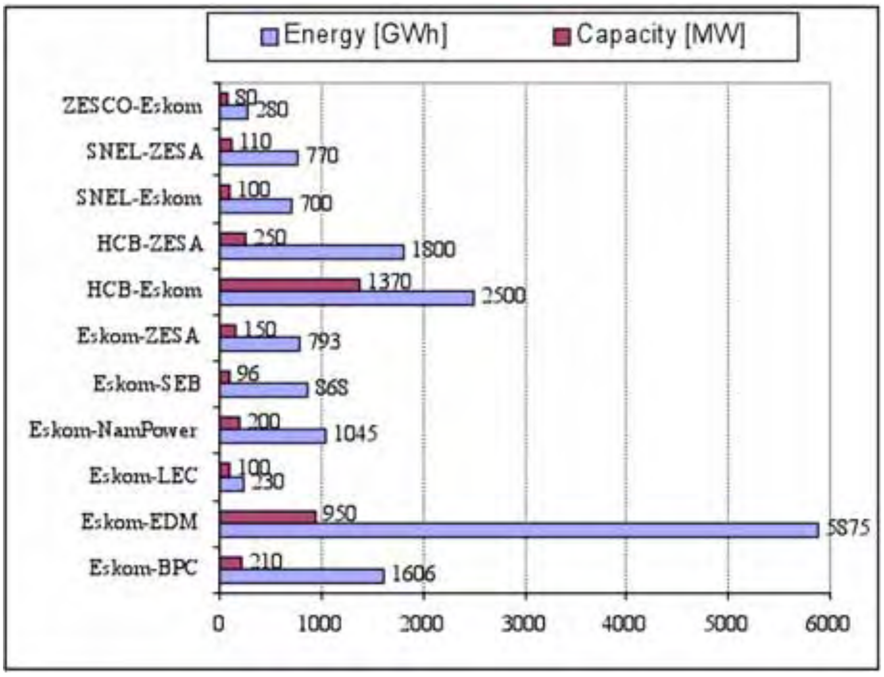
3. SCALING UP REGIONAL ENERGY ACCESS

It is the objective of SAPP to provide a forum for the development of a world class, robust, safe, efficient, reliable and stable interconnected electrical power system in the region including harmonising inter-utility relationships. SAPP is continuously monitoring the generation and transmission projects to ensure that they are on track and timely recommendations are made were delays are noted. To mitigate the risk of drought thermal / hydro coordination is promoted and also to spread the projects in a variety of countries to achieve a regional balance and geographical diversity. Transmission projects are needed to evacuate the power from the generating stations to major load centres in these countries.

Strong ties exist among different countries through bilateral agreements. These have assisted countries that are deficient in generation capacity to meet their local requirements without many disruptions. Figure 1 below shows the bilateral agreements in force from 2006. The volumes of energy traded by each country in term of imports and exports are shown on figure 2.

4. OUTLINE OF THE CURRENT GRID INTERCONNECTIONS AND PROBLEMS ENCOUNTERED IN ENSURING CROSS BORDER ENERGY TRADE

A map will be shown with details of all the major existing transmission lines. Planned projects will also be highlighted. Energy trading parties will be shown with the latest figures for the year. Both bilateral energy trade and the short term energy market trade volumes will be indicated showing the percentage volumes traded. The problems encountered in ensuring cross border trade will be shown and what was done to overcome those problems will be highlighted. Low cost electricity was prevalent during the times when there was excess generation capacity in the region. Starting in 2007 the region has run out of generation surplus capacity. This has also affected the volumes of trade and has lead to high electricity prices.



HCB hydro supply: 1,770MW, Eskom thermal supply: 1,706MW

Figure-1. 2006 Bilateral Contracts in SAPP

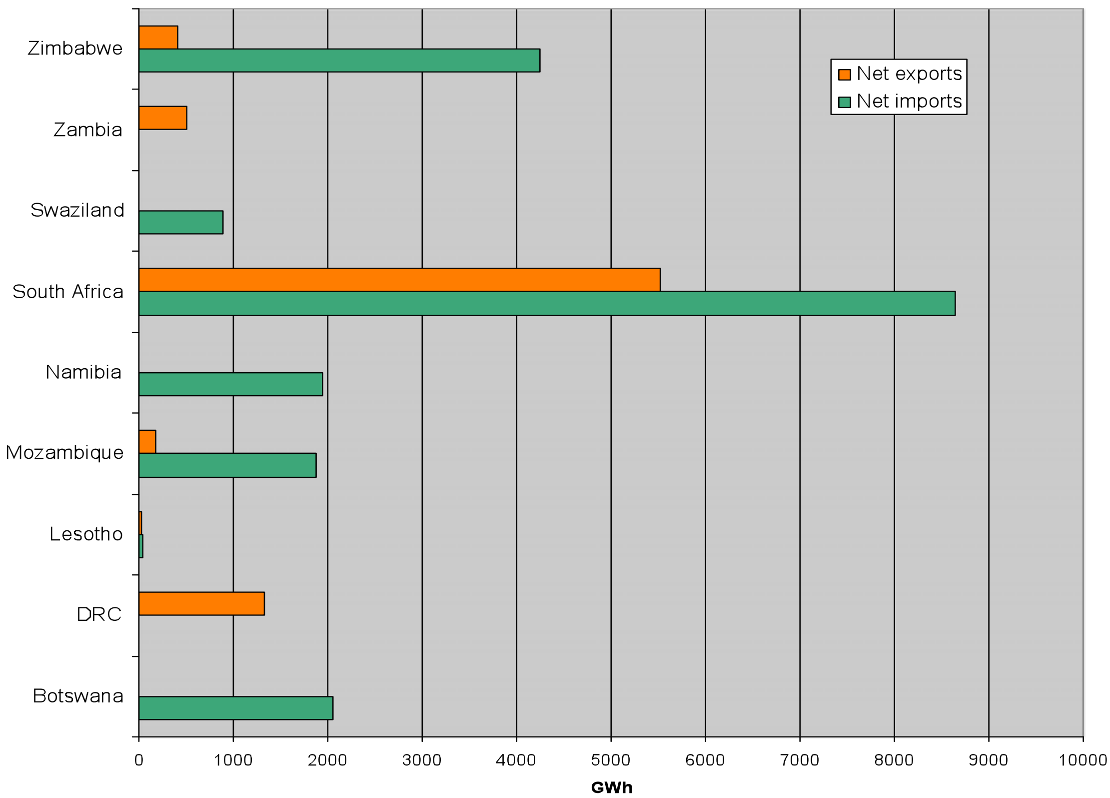


Figure-2. Volumes Traded in SAPP 2006/7

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10. Experiences of Projects for Interconnecting Africa and Challenges

Alison Chikova, SAPP Chief Engineer, SAPP Coordination Centre, Harare, Zimbabwe

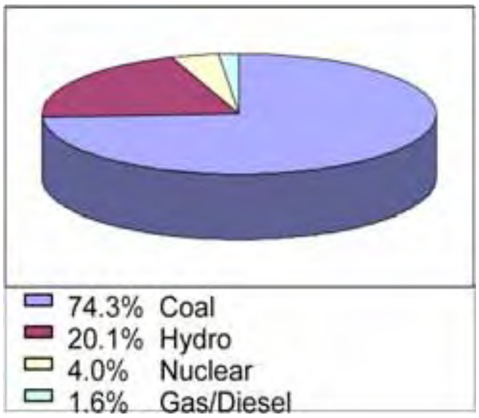
Abstract: The paper will provide an overview of the Southern African Power Pool (SAPP's) experience in the area of planning and developing electricity grid interconnection projects. The main economic and technical benefits that can be gained operating an integrated regional electricity grid will be demonstrated. The paper sets out key challenges that need to be addressed to ensure the reliability and security of electricity supply in the Southern Africa region. The paper will highlight the history of the development of transmission interconnectors in the region. The geographical locations of existing and new transmission projects will be highlighted.

A detailed background of the SAPP Membership, generation technology mix and the peak demand for each country will be analysed and presented.

Keywords: Cross Border Trading, Interconnections

1. WHAT IS SAPP

SAPP is a regional body that was formed in 1995 through a Southern African Development Countries (SADC) treaty to optimise the use of available energy resources in the region and support one another during emergencies. The Power Pool, whose Co-ordination Centre is in Harare, comprises of 12 SADC member countries represented by their respective Electric Power Utilities. The SADC region serves 230 million people. The generation mix is indicated in the following diagram:



2. A BRIEF OVERVIEW OF THE ELECTRIC POWER SECTOR IN SOUTHERN AFRICA

Details of each country will be presented highlighting the potential generation capacity available in the region. The power generation capacity in the region will be presented including new generation and transmission projects in the short to medium term covering the period 2008 to 2013. The challenges to financing the major investment projects will be addressed.

There are significant coal reserves are in Botswana, South Africa, Mozambique and Zimbabwe. South Africa has 54 billion tonnes of coal reserves which represents more than 95% of all SADC coal reserves. Mozambique has not yet utilised this potential for power generation. Hydro power potential is in the North in Mozambique, Zimbabwe, Zambia and the Democratic Republic of Congo.

3. THE HISTORY OF INTERCONNECTIONS

The development of transmission interconnectors in Sub Saharan Africa started in the early 1950's after the construction of the 500 kV HVDC transmission line from Inga power station in the Democratic Republic of Congo to Zambia with a total length of 1700 kilometers. This was followed by the construction of another transmission line across the Zambezi River following the completion of the construction of the Kariba Dam in 1960. In 1975 another HVDC transmission line was commissioned from HCB in Mozambique to Apollo in South Africa (1300 km). These interconnections facilitated electricity trading in SADC but were linked by weak 220 kV transmission network from Zimbabwe to Botswana. The challenge was to strengthen the weak transmission interconnections between these countries and this will be addressed in this paper.

4. NEW TRANSMISSION PROJECTS

Nine out of the twelve SAPP countries are interconnected with each other and this offers a great diversity of power resources from hydro in the north to thermal power in the south. The diversity of resources is being used by utilities in negotiating new power contracts during peak and off peak periods. There is great hydro power capacity in the north in the Democratic Republic of Congo, Zambia and Zimbabwe and in the northern Mozambique. In 1992 the region was hit by a drought and the hydro systems had very little power for their local requirements. This led to negotiations to build a 400 kV transmission interconnector between Zimbabwe and South Africa. South Africa had excess power capacity and was ready to supply the countries in the north. In 1995, the 400 kV transmission interconnector was commissioned. This was a strong link which led to the formation of the Southern African Power Pool as nine countries were interconnected. The new transmission interconnectors have led to utilities exploring new power contracts. The benefits of transmission interconnections will be demonstrated.

Due to the costly nature of power projects, the governments of Africa still do the mobilisation of funds for most projects in the power sector. In order to accelerate the implementation of projects, African power utilities are working together on those projects, which potentially benefit more than one member of the pool. Examples of power projects in SAPP, which have been implemented by more than one national utility, include:

1) The completion of the 400kV Matimba-Phokoje-Insukamini line linking Eskom (South Africa), BPC (Botswana) and ZESA (Zimbabwe) in 1995.
2) The completion of the 330kV transmission line in 1997 between Songo (Mozambique)
3) The restoration of the 533kV DC lines between Cahora Bassa (Songo substation) in Mozambique and South Africa (Apollo substation) in 1998 by Eskom (South Africa) and HCB (Mozambique).

Utilities in the SAPP have realised that by working together on power projects, a lot more could be achieved than working as individual utilities. The implementation process is quickened with shared expertise from the region.

The SAPP Transmission projects are classified in the following categories:

a. Outstanding transmission interconnectors whose aim is to *interconnect non-operating members* of the SAPP to the SAPP grid:

- Malawi-Mozambique 220 kV interconnector,
- Zambia-Tanzania-Kenya Interconnector 330 kV, and
- Interconnection of Angola via the Western Power Corridor Project (WESTCOR).

b. Transmission interconnectors aimed at *relieving congestion* on the SAPP grid, and

- Zimbabwe – Zambia- Botswana- Namibia interconnector,
- The 2nd 420 kV Interconnector between Zimbabwe-Botswana and South Africa

c. New transmission interconnectors aimed to *evacuate power from generating stations* to the load centres**.**

5. SPECIAL PURPOSE VEHICLE TRANSMISSION COMPANY

The paper will also look at a Special Purpose Vehicle transmission company (MOTRACO) set up specifically to wheel up to 950 MW firm power to a dedicated customer which is an aluminium smelter. This company was set up with equal shareholding between three utilities namely Eskom of South Africa, EdM of Mozambique and SEB of Swaziland. Experiences from this company will be shared. Another example would be made of another transmission company in Zambia, the Copper Belt Energy Company (CEC). Wheeling arrangements for this company will also be looked into and how the sharing of transmission wheeling revenue is done between the utility and the private transmission company. These examples will highlight the lessons learnt in the planning and promoting of interconnection projects as means of ensuring reliability and security of electricity supply in Southern Africa.

6. OUTLINE OF THE CURRENT GRID INTERCONNECTIONS AND PROBLEMS ENCOUNTERED IN ENSURING CROSS BORDER ENERGY TRADE

A map will be shown with details of all the major existing transmission lines. Planned projects will also be highlighted. Energy trading parties will be shown with the latest figures for the year. Both bilateral energy trade and the short term energy market trade volumes will be indicated showing the percentage volumes traded. The problems encountered in ensuring cross border trade will be shown and what was done to overcome those problems will be highlighted.

Low cost electricity was prevalent during the times when there was excess generation capacity in the region. Starting in 2007 the region has run out of generation surplus capacity. This has also affected the volumes of trade and has lead to high electricity prices.

7. PLANNING FOR THE TRANSMISSION GRID

The N-1 transmission planning criteria is used in SAPP to ensure a reliable transmission network. This is used for both internal reinforcements and cross border interconnectors. The costs for the interconnections are met by the respective countries unless it is a dedicated transmission line developed by an IPP. Funding for the projects is a major challenge and if projects are identified for meeting regional needs then these are easier to finance.