IEEE POWER ENGINEERING SOCIETY
ENERGY DEVELOPMENT AND POWER GENERATION COMMITTEE

PANEL SESSION: AFRICAN AND MIDDLE EAST ENERGY DEVELOPMENT AND POWER GENERATION ---STATUS OF RENEWABLE ENERGY PROJECTS, SUSTAINABILITY OF INFRASTRUCTURE, LARGE AND SMALL-SCALE DEVELOPMENTS, AND JOINT VENTURE AND CROSS-BORDER PROJECTS[#]

Wednesday 9 a.m.~1 p.m. and 2 p.m ~5 p.m. (To be confirmed)

Tom Hammons, Pat Naidoo and Bai Blyden

IEEE 2007 General Meeting, 24-28 June 2007, Tampa, FL, USA.

Sponsored by: International Practices for Energy Development and Power Generation Subcommittee

Chairs: Tom Hammons, University of Glasgow, Scotland, UK.
Pat Naidoo, ESKOM, South Africa
Bai Blyden, The BBRM Group, LLC, USA

Track 2: Securing New Sources of Energy

INTRODUCTION

On behalf of the Energy Development and Power Generation Committee, welcome to this Panel Session on African and Middle East Energy Development and Power Generation---Electricity Infrastructure: Status of Renewable Energy Projects, Sustainability of Infrastructure, Large and Small-scale Developments, and Joint Venture and Cross-Border Projects

The Panel 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 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 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. The panel seeks to follow the paradigm that contemplates challenges of the 21st century.

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

[#] Document prepared and edited by T J Hammons

present status and prospective trends of African Electricity interconnections and efforts to improve efficiency are very important problems.
The Session presents some results of studies in this area at this time.

Panelists and Titles of their presentations are:

1. Pathmanathan Naidoo, Eskom, South Africa; Ahmed Zobaa, University of Cairo, Egypt, and Lawrence Musaba, Manager, Southern African Power Pool, Harare, Zimbabwe; Fundamental Elements for the Forward Planning of the "*Cape to Cairo*" Interconnected Power System (Paper 07GM 0636).

2 Pathmanathan Naidoo, Eskom, South Africa, BPC; and J.T.Lokala, Westcor, Gaborone, Botswana. Defining the Terms of Reference for Feasibility Studies for the Western Power Corridor Project in Southern Africa. (Invited Discussion).

3. Pathmanathan Naidoo, Eskom South Africa; and Nelson M. Ijumba, HVDC Center, University of KwaZulu, Natal, Durban, 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 Discussion).

4. Adnan Al-Mohaisen, General Manager, GCC Interconnection Authority, Saudi Arabia; Luc Chaussé, Project Director, Transmission & Distribution Division, SNC–Lavalin Inc. and Satish Sud, Vice President, Power Systems Energy Division, SNC-Lavalin Inc., Montreal, Quebec, Canada. Progress Report on the Gulf Cooperation Council (GCC) Electricity Grid System Interconnection in the Middle East (Paper 07GM0456).

5. Pathmanathan Naidoo, Eskom, South Africa; Lawrence Musaba, Southern African Power Pool, Harare, Zimbabwe; Fernando Sousa, Electricidade de Mocambique, Mozambique; and Mark Dingle, Eskom South Africa. Planning the Eastern Power Corridor of Southern Africa (Paper 07GM0743).

6. F. Masawi, Motraco, Mozambique; Pathmanathan Naidoo and W. Majola, Eskom South Africa; and T. J. Hammons, Glasgow University, UK. Analysis of Performance of an African Joint Venture Company Established for the Transport of Bulk Power from Eskom, South Africa to Swaziland, Mozambique and the Mozal Aluminum Smelter in Maputo (Paper 07GM1285).

7. Tom Sparrow and Brian Bowen, Purdue University, USA. Hydropower Planning in Egypt, Sudan and Ethiopia. (Invited Discussion).

8. Katherine Steel, MIT, USA. A System Dynamics Approach to Understanding the Development of the Kenyan Electric Power Sector (Paper 07GM0967).

9. Stephen R. Connors, Director, MIT Laboratory for Energy and the Environment, MIT, Cambridge, MA, USA. Providing Electricity Services to Rural Africa (Paper 07GM1035).

10**.** Bai Blyden, Engineering Consultant, BBRM Group, Elk Grove, CA, USA. Exploring a Systems Dynamics Approach to Institutional Development and Integration in the African Power Development Sector (Paper 07GM0915).

11. Pathmanathan Naidoo, D. Muftic and A.C. Britten, Eskom, South Africa; N. M. Ijumba, University of KwaZulu, Natal, South Africa, C. T. Gaunt, University of Cape Town, South Africa; and

T. J. Hammons, Glasgow University, UK. Considerations for the Planning of UHVDC Schemes in Southern Africa (Paper 07GM1309).

12. Wei-Jen Lee, Energy Systems Research Center, University of Texas at Arlington, TX, USA; Bai Blyden, BBRM Group, Elk Grove CA, USA; and Alusine Jalloh, Evaluating Autonomous Systems with Hybrid Generation Facilities in support of Fishing Villages (Paper 07GM1327).

13. Invited Discussers

Each Panelist will speak for approximately 20 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 Tom Hammons (Chair of International Practices for Energy Development and Power Generation, University of Glasgow, UK), Pat Naidoo (Senior General Manager [Special Projects], Office of the Chief Executive, Eskom, South Africa), and Bai Blyden (Engineering Consultant, BBRM Group, LLC, USA).

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

PAPER ABSTRACTS

Paper 1

FUNDAMENTAL ELEMENTS FOR THE FORWARD PLANNING OF THE "CAPE TO CAIRO" INTERCONNECTED POWER SYSTEM

Pathmanathan Naidoo, Eskom, South Africa; Ahmed Zobaa, University of Cairo, Egypt, and Lawrence Musaba, Manager, Southern African Power Pool, Harare, Zimbabwe

Abstract: South Africa continues to set the international benchmark for electricity prices. South Africa also provides the largest percentage of the electricity used on continental Africa. Based on this historical strength of favorable electricity prices, the plans are to even lower the prevailing electricity prices by adding more hydro-based renewable energy with mid merit and peaking support from environmentally friendly gas based generation. There exists a sufficient quantity of both gas and hydro at acceptable and affordable rates. The first building block of the continental grid would be the regional interconnected power system of the regional power pools. The next building phase will involve the use of extra high voltage DC for bulk power transfer between the participating regional power systems. The expected result is sharing in the diversity in primary energy sources; all contributing to a lower end user cost of electrical energy. Together with Africa's richness in resources, the continent has the capability to become the energy intensive valley of the world; supporting the developed world in the ongoing battle with global warming.

Paper 2

DEFINING THE TERMS OF REFERENCE FOR FEASIBILITY STUDIES FOR THE WESTERN POWER CORRIDOR PROJECT IN SOUTHERN AFRICA (INVITED DISCUSSION)

Pathmanathan Naidoo, *Eskom South Africa* and J.T.Lokala, *Westcor, Gaborone, Botswana*

Abstract: The return of peace and stability to Southern Africa has promoted a surge in growth of customer demand for electrical energy. The region boasts some of the best renewable hydro energy sources coupled with the environment teaming with wild life, game, fauna and flora. Balancing growth requirements with environmental impact concerns have promoted a two-part feasibility assessment of the proposed Western Power Corridor project in Southern Africa. Supported by the regularity of water flows, a run of river power station is proposed at the Inga 3 site on the Congo River. For large-scale bulk power evacuation, extra high voltage direct current transmission will be a requirement. This paper introduces the large-scale project and defines terms of reference for the feasibility studies.

Paper 3

A NOVEL APPROACH TO PROVIDING ON-ROUTE POWER SUPPLIES TO RURAL AND URBAN COMMUNITIES IN CLOSE PROXIMITY TO EXTRA HIGH VOLTAGE DC TRANSMISSION LINE (INVITED DISCUSSION)

Pathmanathan Naidoo, *Eskom South Africa*; and Nelson M. Ijumba, *HVDC Center, University of KwaZulu, Natal, Durban, South Africa*

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 be provided affordably. Laboratory based studies of HVDC sources have shown that conventional corona cages can capture corona energy and 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 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.

Paper 4

PROGRESS REPORT ON THE GULF COOPERATION COUNCIL (GCC) ELECTRICITY GRID SYSTEM INTERCONNECTION IN THE MIDDLE EAST

Adnan Al-Mohaisen, *General Manager, GCC Interconnection Authority, Saudi Arabia*; Luc Chaussé, *Project Director, Transmission & Distribution Division, SNC–Lavalin Inc*. and Satish Sud, *Vice President, Power Systems Energy Division, SNC-Lavalin Inc., Montreal, Quebec, Canada*

Abstract: This paper describes the strategy adopted for implementation of the interconnection between the Gulf States (Kuwait, Saudi Arabia, Bahrain, Qatar, UAE and Oman) to ensure a competitive price for the project. The paper also describes progress in the implementation and the issues which have had to be faced to date. In parallel, activities are being carried out to define the organizational structure of the GCCIA and the interconnection agreements that will provide the framework for the operations.

Paper 5

PLANNING THE EASTERN POWER CORRIDOR OF SOUTHERN AFRICA

Pathmanathan Naidoo, *Eskom, South Africa*; Lawrence Musaba, *Southern African Power Pool, Harare, Zimbabwe*; Fernando Sousa, *Electricidade de Mocambique*, Mozambique; and Mark Dingle, *Eskom South Africa*

Abstract: The eastern corridor of Southern Africa has hydro, gas and thermal energy sources. Emanating from the South African National Grid thermal power stations, two 400kV transmission lines connect the port City of Maputo and the Swaziland Edwaleni substation to form the first part of the proposed Eastern Corridor. This is with the joint venture company, Motraco. From Maputo, the lines can run northwards to the port city of Beira and then onto Cahorra Bassa hydroelectric power station. Cahorra Bassa supplies Zimbabwe, Mozambique and South Africa and planned Malawi. This power station has the potential for expansion at the North Bank. Lower downstream, another power station, Mpanda Unuca is proposed. Interconnecting these power stations will provide a very strong base for further extensions northwards to Dar-es-Salaam and with a DC tee –off to Madagascar. Madagascar is an island load off continental Africa. At Dar Es Salaam, opportunities exist for further extensions northwards towards Uganda and Kenya. In addition to the thermal and hydro energy sources, gas could also enter the power generation sector. At present, gas in imported by the Sasol Plant, in South Africa, as primary feedstock into the coal to gas to liquid petroleum conversion process.

Paper 6

ANALYSIS OF PERFORMANCE OF AN AFRICAN JOINT VENTURE COMPANY ESTABLISHED FOR THE TRANSPORT OF BULK POWER FROM ESKOM, SOUTH AFRICA TO SWAZILAND, MOZAMBIQUE AND THE MOZAL ALUMINUM SMELTER IN MAPUTO

F. Masawi, *Motraco, Maputo, Mozambique;* P. Naidoo and W. Majola, *Eskom South Africa*, and T. J. Hammons, *Glasgow University, UK.*

Abstract: The quality of electricity supply delivered to the national utilities in Mozambique and Swaziland and the energy intensive customer, BHP Billiton–Mozal aluminum smelter is defined as world class. Two series compensated 400 kV transmission lines provide the 1200 MW of electrical energy to the participating customers. The joint venture company collated the skills and experiences of the shareholders and directed the focused effort to achieve the sterling business results. Customer satisfaction has contributed to application for more power.

Paper 7

HYDROPOWER PLANNING IN EGYPT, SUDAN AND ETHIOPIA (INVITED DISCUSSION)

Tom Sparrow and Brian Bowen, *Purdue University, USA*

Abstract: Over the past few years the East Africa region has been promoting the creation of an East African Power Pool (EAPP). The Ethiopian Electric Power Corporation (EEPCO), plans to construct several new generating facilities. Kenya's over-reliance on hydroelectricity and the effects of prolonged

droughts provide the background for the construction of the Olkaria II geothermal station. Uganda is an electricity exporter to Kenya and plans to significantly raise its level of exports into Tanzania and Rwanda. Sudan's additional generating capacity at the Nile's fourth cataract, with the Merowe facility of 1,000MW, and improvements to the nation's grid in the Blue Nile Grid and the Western grid sections are strategic initiatives for the East African electricity industry. .

The Purdue energy modeling team has been invited by Electricite de France (EDF) to participate in the USAID funded regional electricity infrastructures project.. A project commencement date is not yet settled."

Paper 8

A SYSTEM DYNAMICS APPROACH TO UNDERSTANDING THE DEVELOPMENT OF THE KENYAN ELECTRIC POWER SECTOR

Katherine Steel, *MIT, USA*

Abstract: In many African countries there is a tension between grid and off-grid electric service provision and it is unclear whether a centralized or decentralized power system architecture will emerge. This paper explores some of the dynamics of system development in Kenya, where poor grid infrastructure has resulted in a thriving private market for photovoltaic panels and a growing number of industries are investigating shifting to on-site generation. The research is based on ethnographic interviews and observations in Kenya and uses System Dynamics modeling tools to analyze qualitative and quantitative feedback in the system.

Paper 9

PROVIDING ELECTRICITY SERVICES TO RURAL AFRICA.

Stephen R. Connors, *MIT, Cambridge, MA, USA*

Abstract: The international community has set ambitious goals aimed at improving the quality of life in Africa. Initial delivery of electric service to rural Africa is far from a "one size fits all" technical solution, especially given the seasonal diversity of energy needs, as well as the availability and quality of candidate renewable energy resources. Nor will be the expansion, and potential integration, of those systems over time be a simple task.

To design, implement and operate cost-effective and reliable rural electricity systems many factors must be taken into account. The technical and economic feasibility of different systems is highly dependent on a diverse set of design criteria: local energy demands (daily, seasonal); available renewable resources (quantity and quality); location relative to conventional fuel supplies and/or grid power; plus how these factors may vary over time. Dynamics among technical and institutional aspects are key, as are understanding the relative economic value of staged electric service introductions. Key design factors towards the deployment of electricity services will be identified and assessed.

Paper 10

EXPLORING A SYSTEMS DYNAMICS APPROACH TO INSTITUTIONAL DEVELOPMENT AND INTEGRATION IN THE AFRICAN POWER DEVELOPMENT SECTOR

Bai Blyden, *Engineering Consultant, BBRM Group, Elk Grove, CA, USA*

Abstract: This paper attempts to further the development of previous recommendations made for institutional and manpower development efficiency to support the growing African Energy Sector. Developing and standardizing a curriculum at strategically selected technical centers and universities throughout the countries of the various regional power pools are the compelling strategic recommendation of this study. Towards this end, this paper introduces an exploratory Systems Dynamics approach to further develop a previously proposed All Africa integration model (1994, 1995). Concepts from Systems Engineering are also used to strengthen the thesis that African Policy makers can effectively capture and leverage the information mass created by the planning and development of some of these Power Generation and Transmission initiatives to develop policies and standards across a spectrum of associated disciplines. Data from ongoing projects across a wide generation profile and fuel mix in the South African power pool (SAPP) and West African Power Pool (WAPP) are good primary candidates for modeling. Their evaluation includes manpower deficiencies; environmental issues, Grid fortification and regional integration and domestic challenges brought on by increasing Load Demand outpacing Generation. Future integration with Central African Power Pool (CAPP), East African Power Pool (EAPP) and interconnection initiatives in North Africa with ties to the Middle East are also discussed.

Paper 11.

CONSIDERATIONS FOR THE PLANNING OF UHVDC SCHEMES IN SOUTHERN AFRICA

Pathmanathan Naidoo, D. Muftic and A.C. Britten, *Eskom, South Africa*; N. M. Ijumba, *University of KwaZulu, Natal, South Africa*; C. T. Gaunt, *University of Cape Town, South Africa*; and T. J. Hammons, *Glasgow University, UK*

Abstract: This paper describes a simple approach to the planning of long distance electric power transmission systems for Southern African conditions. In common with China and India, significant sources of hydroelectric generation in Southern Africa are situated far form the main load centres. This applies particularly to the single site large hydroelectric resource of 44GW at Inga on the Congo River in the Democratic Republic of Congo and to the more than 100GW distributed sources across Central, West and East Africa.. In all cases, the nearest major load centres are about 3000 to 6000 km away. The salient question is how to reliably and securely transport high power levels of up to 6 GW over this distance. This paper describes the results of the preliminary investigations into developing the transmission master plan for the Western Power Corridor project in Southern Africa.

Paper 12

EVALUATING AUTONOMOUS SYSTEMS WITH HYBRID GENERATION FACILITIES IN SUPPORT OF FISHING VILLAGES

Wei-Jen Lee, *Energy Systems Research Center, University of Texas at Arlington, TX, USA*; Bai Blyden, *BBRM Group, Elk Grove CA, USA*; and Alusine Jalloh, *The African Program, University of Texas at Arlington, TX, USA*

Abstract: 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. 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. In addition to regional cooperation and integration through energy pooling and cross-border energy trading, a balanced Distributed Generation strategy through modified microgrids has been proposed in the previous discussion [1]. This paper serves as continuation of a distributed micro grid application specific to small towns and villages fishing processing potential. 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.

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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.

Pathmanathan (Pat) Naidoo is a registered professional engineer, a member of SAIEE and IEEE, a graduate in Electrical Engineering from the University of Durban Westville in South Africa and a postgraduate with an MBA from Samford University in the USA. Presently, Mr. Naidoo is an engineering doctorate student with the Da Vinci Institute for Technology Management.

With twenty-one years of in service experience with Eskom, South Africa, Pat Naidoo is currently the Senior General Manager for Eskom, a member of the Transmission Board and of the Operations Committee of Eskom. In 1994, he received the South African Institute of Electrical Engineers young achievers award. He is married, has two sons and when not at work he enjoys sports, gym and participating in cultural music and drama.

Bai K Blyden is an Engineering Consultant with the BBRM Group, LLC, USA. Bai Blyden received the degree of MS.EE from 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 (45 MW) 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.

FULL PAPERS

Received February 5 2007

1. FUNDAMENTAL ELEMENTS FOR THE FORWARD PLANNING OF THE "CAPE TO CAIRO" INTERCONNECTED POWER SYSTEM (PAPER 07GM 0636).

P. Naidoo[1], *Eskom South Africa*, A. Zobaa, *Cairo University, Egypt* and L.Musaba, Southern African Power Pool, *Harare, Zimbabwe.*

Abstract: South Africa continues to set the international benchmark for electricity prices. South Africa also provides the largest percentage of the electricity used on continental Africa. Based on this historical strength of bulk electricity production and delivery at favourable electricity prices, the plans are to even lower the prevailing electricity prices by adding more hydro based renewable energy with mid merit and peaking support from environmentally friendly gas based generation. There exists a sufficient quantity of both gas and hydro at acceptable and affordable rates. The first building block of the continental grid would be the regional interconnected power system of the regional power pools. The next building phase will involve the use of extra high voltage DC for bulk power transfer between participating regional power systems. The expected result is the sharing in the diversity in primary energy sources; all contributing to a lower end user cost of electrical energy. Customer competitiveness in global markets, lower primary energy costs, highest quality and reliability of supply and customer satisfaction are the fundamental elements to be included in the forward planning of the "Cape to Cairo" interconnected power system. Together with Africa's richness in resources, the continent has the capability to become the energy intensive valley of the world; supporting the developed world in the ongoing battle with global warming.

I. INTRODUCTION

Eskom South Africa continues to deliver sterling performance from the installed capacity base of 42GW. On average, the price of electrical energy sent out to the industrial and mining customers' sets the international benchmark [1]. This position emanates from the intelligent engineering use of low-grade thermal coal in clinically clean production facilities; arranged in packs of 6 machines of nameplate rating of 600 MW. The total energy sent out and waste output fully complies with international environmental specifications. The quality of supply is delivered to international standards. The economies of scale driven production have contributed to energy intensive customer competitiveness in the global markets. This position is strategically important to Africa given the vast deposits of natural resources. The South African customer competitive position needs to be sustained and shared with neighboring countries such that eventually the continent Africa would mirror the benchmark set by South Africa. A fundamental element for the forward planning of the "Cape to Cairo" interconnected power system is certainly the promotion and sustainability of customer competitiveness in the global markets. This is achievable by employing lower cost energy sources, environmentally friendly generation production and reliable and dependable power delivery at acceptable quality of supply.

The proposal for Africa is no different from the rest of the world. The industrialized G 8 group of countries all have interconnected power systems; generally national interconnections supported by cross border regional interconnections and in some cases even international interconnections. Hingorani and Gyugyi note that this is done for economic reasons; to reduce the cost of electricity and to improve the reliability of the power delivered [2]. "Interconnections pool power plants and load centers and offers a

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minimized total power generation capacity and primary energy fuel cost. Power system Interconnection is an alternative generation resource; less interconnection means that more generation resources are required. They conclude that in a deregulated electric service environment, an effective electric grid is vital to the competitive environment of reliable electric service". [2]. This conclusion from literature review concurs with our earlier conclusion to make customer competitiveness a fundamental element in the forward planning of the "Cape to Cairo" interconnected power system.

In general, the electricity supply industry has generally been a state owned entity, with processes being supply driven and supported by regulated tariffs. In the case of Africa, every country on the continent promotes state ownership. The industry is vertically integrated and is supported by some form of regulation. Even in this monopoly model, a customer driven agenda is required; lower and affordable prices together with acceptable quality of supply.

II. PROMOTING THE USE OF LOWER COST PRIMARY ENERGY SOURCES

The available energy sources in Africa [3] is primarily made up of thermal coal, natural oil and gas and renewable hydro. Thermal is dominant in Southern Africa, Hydro is dominant in Central Africa with smaller capacities in the South, East and West Africa whilst natural oil and gas dominates West and North Africa. Total installed capacity is approximately 100 GW with 50 GW in Southern Africa, 30 GW in North Africa and the remaining 20 GW spread across West, East and Central Africa [3]. The net diversified sent out capacity is about 50 GW at 0,5-load factor. Other renewable energy sources such as wind, solar, tidal and wave are either not economically available or has not been developed to the point of economic viability and is still an unknown potential source. Aside from natural oil and gas which has other demanding energy markets, Southern and Central Africa's thermal coal and renewable hydro is available in abundance and at the lowest cost or at no cost as primary fuel.

If we set Southern and Central Africa's primary energy source as the competitive economic foundation for Continental Africa's lower cost energy, we will probably be 90% correct if an actual research study is undertaken of primary energy costs at each site on Continental Africa. The remaining 10% would be available as complimentary contribution to the overall lower cost outcome. This approach directly supports the expectation of customer competitiveness in the global markets.

Much of Central Africa's renewable hydro capability is not yet developed. Given the void in operating data from Central Africa, we can select Southern Africa to be the benchmark for Africa. This also includes Eskom South Africa as the international benchmark for customer competitiveness in the global markets. The Southern African Power Pool, commenced in 1995 following South Africa's re-admittance to the international community, is now a mature power pool with well-defined vision and objectives. From their annual report of 2006 [4], we record their vision and objectives as follows:
The vision consists of a competitive electricity market, choice of electricity supplier for end users, regional choice for investment by energy intensive customers and promoting sustainable energy development through sound economic, environmental and social practices.
The objectives consists of the development of a world class, robust, safe, efficient, reliable and stable interconnected power system, to measure and enforce standards of quality of supply, to harmonize relations between member utilities, people development and rural electrification.
Both the vision and objectives contribute to and form part of the fundamental elements for the forward planning of the " Cape to Cairo" interconnected power system. It is recommended that these elements be included in the founding statements of the power pools being established across Africa.

For the primary energy sources, the selection of Southern Africa's thermal coal and the renewable hydro of the Congo River, the Medico Quanza River in Angola and the Zambezi river would provide collectively the lowest cost energy source. Testimony is South Africa's international benchmark and the no cost concession for the use of the waters in the development of the Westcor Project.

III. THE INTERCONNECTED REGIONAL POWER POOLS

From the literature review and based on the work of Chard [5] , we record the following general attributes of interconnected power systems; all of which is directed to the least cost of electricity production.

(a) It promotes effective pooling of all generation plant including stand by plant
(b) It ensures that heavy demands in one locality can be supported by generation from a neighboring locality
(c) It assists continuity of supply in the event of generation outages either planned or unplanned by transferring load service to a neighboring area
(d) It allows only the most efficient and economical power plants to be operated
(e) It allows for diversity in loading to be serviced economically

From the general attributes of interconnection, it is clear that the transmission system that interconnects the power stations are in fact part of the generation system; an extension of the power station busbar. Much work has occurred in terms of establishing the regional power pools. There are five power pools in Africa, viz. The Central African Power Pool (CAAP), COMELEC of North Africa, East African Power Pool (EAPP), West African Power Pool (WAPP) and Southern African Power Pool (SAPP). The parties are working together to common policies and procedures; all directed to an integrated market for all of Africa.

The regional power pools will bring to the market all the local lowest cost energy sources and will simultaneously provide access and interconnectivity for all the local load centers. The next step is to tie together the various regional power pools such that all of Africa can share lower cost energy sources and collectively make the continent the choice for investors and customer competitiveness. Pooling all of Africa together will promote the economies of scale that will be required to compete with the developed world and the developing giants of China, India and Brazil. It will be folly for individual African countries or regions to go it alone as the benefits of economies of scale are substantial.

IV. INTEGRATING REGIONAL POWER POOLS WITH HIGH AND EXTRA HIGH VOLTAGE DC

The regional power pools effectively become point sources and loads. Given the large distance between power pools, sources and loads, it is recommended that DC technology be considered for the task of bulk power transfers. Figure 1 shows how such interconnection could be accomplished and for all the power pools to be integrated.

Preliminary studies with 800 kV DC show that for distances of 3000km, 3 GW can be transferred and power losses are substantial at 500 MW. A higher operating voltage at say 1200 MV could be a future option as the technology is presently not available.

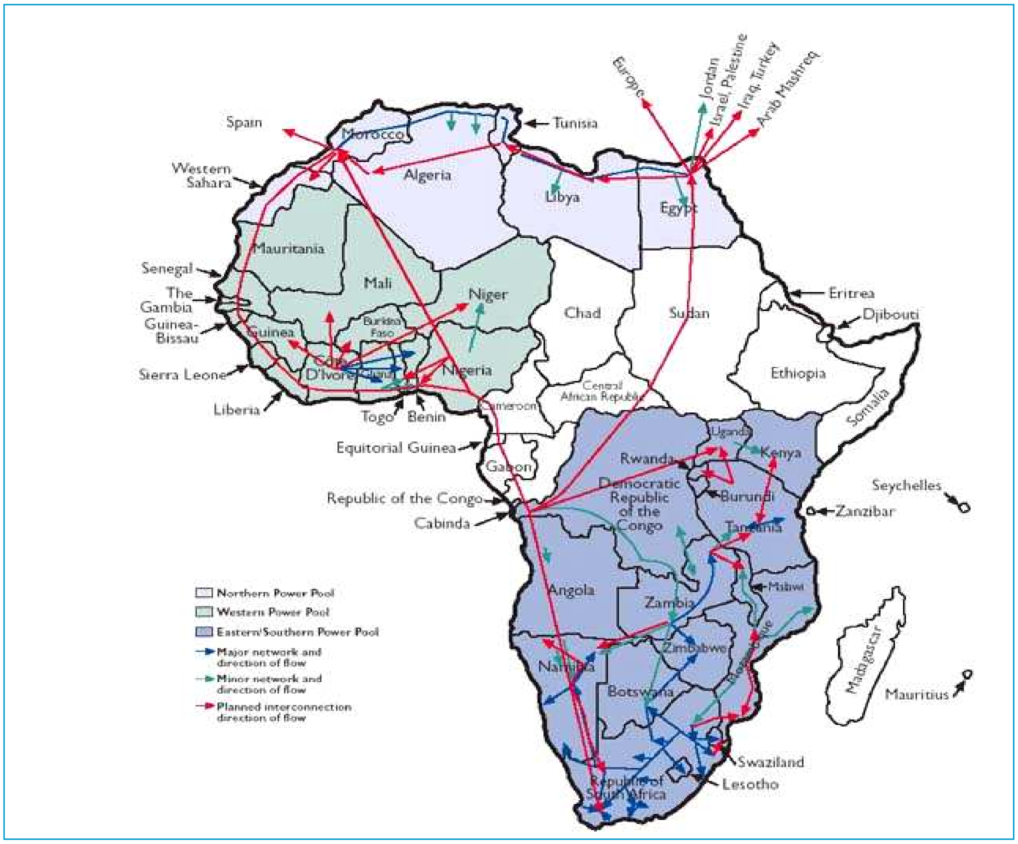

Figure 1: African Grid and Continental Interconnections

V. CONCLUSION

A classical planning approach is recommended with the added sensitivity of sustaining the globally competitive benchmark for world electricity prices. The power pool model for local interconnections and the use of inter pool energy transfers using EHVDC or UHVDC for continental interconnections are key elements that can support the constraint of sustained worlds lowest cost electricity prices. The approach presented is unique but practical.

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2 DEFINING THE TERMS OF REFERENCE FOR FEASIBILITY STUDIES FOR THE WESTERN POWER CORRIDOR PROJECT IN SOUTHERN AFRICA. (INVITED DISCUSSION)

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J.T.Lokala, Westcor, Gaborone, Botswana

Abstract: The return of peace and stability to Southern Africa has promoted a surge in growth of customer demand for electrical energy. The region boasts some of the best renewable hydro energy sources coupled with environments teaming with wild life, game, fauna and flora. Balancing growth requirements with environmental impact concerns have promoted a two-part feasibility assessment of the proposed Western Power Corridor project in Southern Africa. Supported by the regularity of water flows, a run of river power station is proposed at the Inga 3 site on the Congo River. For large-scale bulk power evacuation, extra high voltage direct current transmission will be a requirement. This presentation introduces the large-scale project and defines the terms of reference for the feasibility studies.

Received February 5 2007

3. 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 DISCUSSION)

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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 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.

Received December 1 2006

4. PROGRESS REPORT ON THE GCC ELECTRICITY GRID SYSTEM INTERCONNECTION IN THE MIDDLE EAST (PAPER 07GM0456).

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Abstract **–** This paper describes the strategy adopted for implementation of the interconnection between the Gulf States (Kuwait, Saudi Arabia, Bahrain, Qatar, UAE and Oman) to ensure a competitive price for the project. This paper also describes the progress in the implementation and the issues which have had to be faced to date. In parallel, activities are being carried out to define the organizational structure of the GCCIA and the interconnection agreements which will provide the framework for the operations.

Index Terms **–** interconnection, grid systems, HVDC back-to-back converter, 400 kV transmission, GIS substations, submarine cable, project financing, project implementation.

I. INTRODUCTION

The planning studies to determine the feasibility and the nature of the interconnection between the six Gulf States were described in References [1 & 2]. Recognizing the benefits of interconnection of their power grids, the six Arab states decided to build an AC interconnection of the 50 Hz systems of Kuwait, Bahrain, Qatar, UAE and Oman with a back-to-back HVDC interconnection to the 60 Hz Saudi Arabian system and this was reported in the IEEE panel session in San Francisco in 1994 [3].

However, it took several years before the GCC Interconnection Authority (GCCIA) was established and the feasibility study had to be updated [4]. The interconnection was justified based on reserve sharing between the systems but once built will provide the opportunity for trading electricity between the member countries.

Agreement had to be reached on cost sharing and financing before the Project could proceed towards implementation. After investigating different options for financing the Project, it was decided to finance the Project with funds from the member countries. The various hurdles to be overcome before the Project could go to implementation were described in the IEEE panel session in Montreal [5]. The implementation of the Project is now underway.

For implementation, the project was broken into discrete contracts which allowed a number of prequalified International contractors to participate in the implementation of the project. The contractors will work concurrently but independently from one another. The proposed implementation strategy for the Project enabled wide participation by International contractors in the shared implementation of the GCC Project in an efficient and economic manner.

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In 2005 requests for Tenders were issued to pre-qualified tenderers for the major work packages: Transmission lines; GIS substations; HVDC Back-to Back; Submarine cable and the Control Centre including protection and telecommunication. Tenders were received and analyzed and contracts were awarded in November 2005. The Project schedule calls for the Interconnection to be in operation by early 2009.

II. THE INTERCONNECTION PROJECT

The electrical grid system interconnection between the GCC states is shown diagrammatically in Figure 1.

FIGURE 1. APPROXIMATE ROUTE AND LAYOUT OF THE GCC INTERCONNECTION

The capacity of the Interconnection to each of the countries is given in Table 1:

TABLE 1. SIZE OF INTERCONNECTION TO EACH GCC STATE

System	Size (MW)
Kuwait	1200
Saudi Arabia	1200
Bahrain	600
Qatar	750
UAE	900
Oman	400

A conceptual diagram of the Interconnection Project is shown in Figure 2.

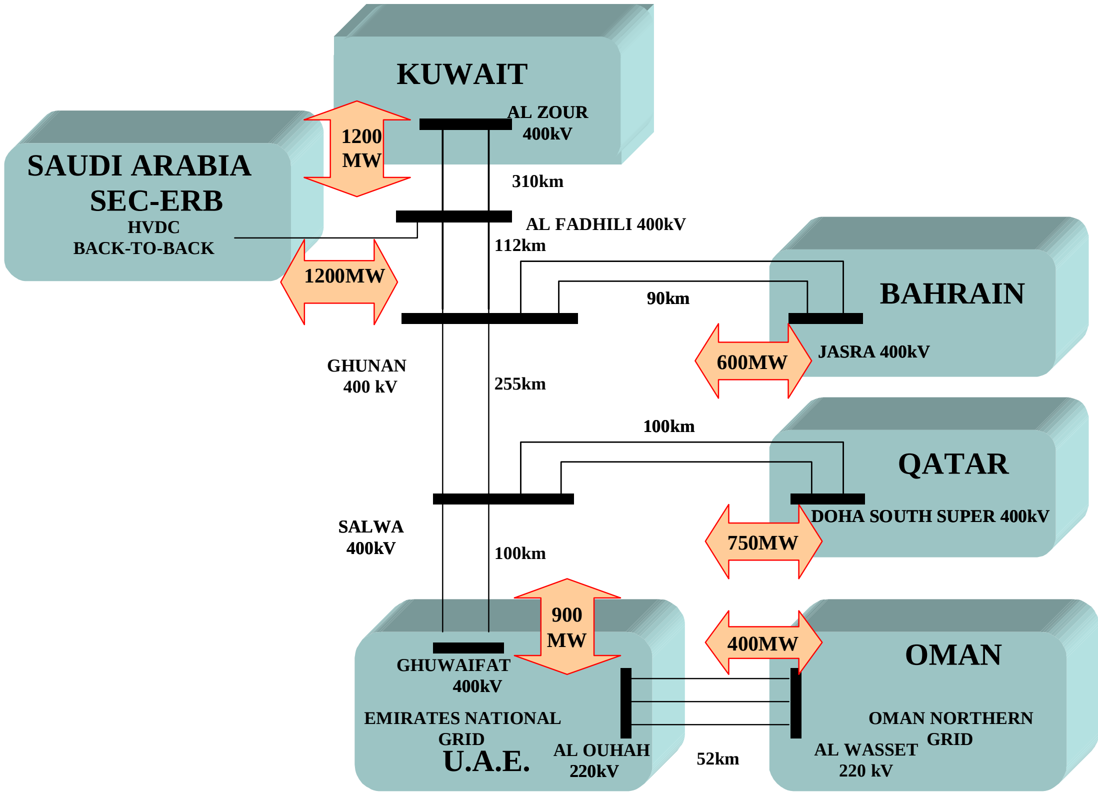

FIGURE 2. CONCEPTUAL DIAGRAM OF THE INTERCONNECTION SYSTEM

The Interconnection Project will be implemented in three phases and consists of the following principal elements:

Phase I: Interconnection of the Northern Systems (Kuwait, Saudi Arabia, Bahrain and Qatar) to be completed in early 2009

- A double-circuit 400 kV, 50 Hz line from Al Zour (Kuwait) to Ghunan (Saudi Arabia) with an intermediate connection at Fadhili (Saudi Arabia) and associated substations.
- A back-to-back HVDC interconnection to the Saudi Arabia 380 kV, 60 Hz, system at Fadhili.
- A double circuit 400 kV comprising overhead lines and submarine link from Ghunan to Al Jasra (Bahrain) and associated substations.
- A double circuit 400 kV line from Ghunan to Salwa (Saudi Arabia) and associated substations.
- A double circuit 400 kV line from Salwa to Doha South (Qatar) and associated substations.
- A Control Centre located at Ghunan.

Phase II: The internal interconnection of the Southern Systems (UAE and Oman) to form the UAE National Grid and the Oman Northern Grid (GCCIA is not involved in this Phase).

Phase III: Interconnection of the Northern and Southern Systems in 2010.

- A double circuit 400 kV line from Salwa to Ghuwaifat (UAE) and associated substations.
- A double and a single circuit 220 kV line from Al Ouhah (UAE) to Al Wasset (Oman) and associated substations.

A simplified single line diagram of the system is shown in Figure 3.

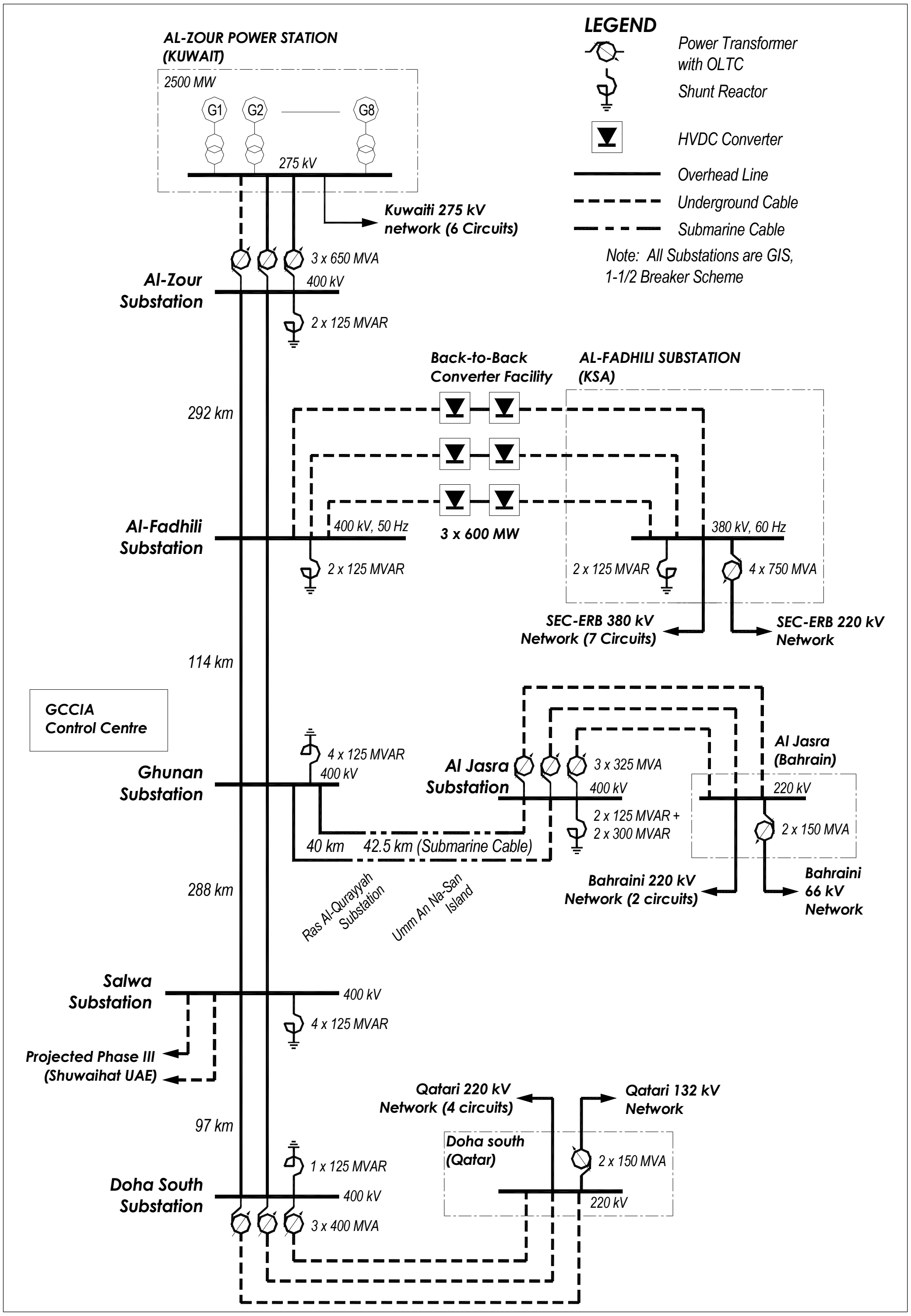

FIGURE 3. SIMPLIFIED SINGLE LINE OF THE INTERCONNECTION – PHASE I

III. IMPLEMENTATION STRATEGY

The GCC Interconnection, Phase I comprises the installation of six (6) high voltage interconnected substations plus a back-to-back HVDC terminal interfacing with four (4) existing substations which belong to the national networks of the respective member Countries. These are concurrently required to effect the exchange of power between the power systems of Kuwait, Saudi Arabia, Bahrain and Qatar.
A Control Center for the GCC Interconnection, which is also capable of communication with the National or Regional Centers of the Member Countries, will also be installed and, when eventually completed, the interconnected substations will be suitable for operation in a coordinated and stable manner through this Control Center. The Center will provide the remote control and monitoring of the substations which will be suitable for unattended operation.

The design and installation of the interconnection facilities: substations, transmission lines and submarine cables, will provide for uniformity and compatibility of functions and allow efficient operation as an independent network, of all the corresponding elements of the interconnection system.

For implementation purposes, the project was broken into discrete contract packages which allowed a number of pre-qualified International contractors to participate in the implementation of the project. The contractors will work concurrently but independently from one another. The proposed implementation strategy for the Project enabled wide participation by International contractors in the shared implementation of the GCC Project in an efficient and economic manner.

Thus, the request for Tenders for the six (6) contracts for GIS substations, one (1) for a back-to-back HVDC station, four (4) contracts for transmission lines, one (1) contract for submarine and land cables were separately issued.

Bidders were allowed to offer combination bids for more than one of the packages and offer combination discounts. To qualify, however, individual bids had to be made and the advantages of combination were evaluated on receipt of bids.

Additionally, a global contract, for the Control Center complete with overall system control and protection, was issued separately. This strategy enabled the selected contractor to offer one fully integrated protection, control, monitoring and communication network based on the latest LAN/WAN network philosophy and using the appropriate network protocols for data access between the stations and the Control Center as well as interchange of data between the GCCIA and the EMS dispatch centers of the different countries. These modern network functions will enable full data retrieval for fault, maintenance and defect analysis at a number of locations to ensure that all aspects of the GCC network are kept in top working order at all times.

The management of the EPC contracts is shown schematically in Figure 4.

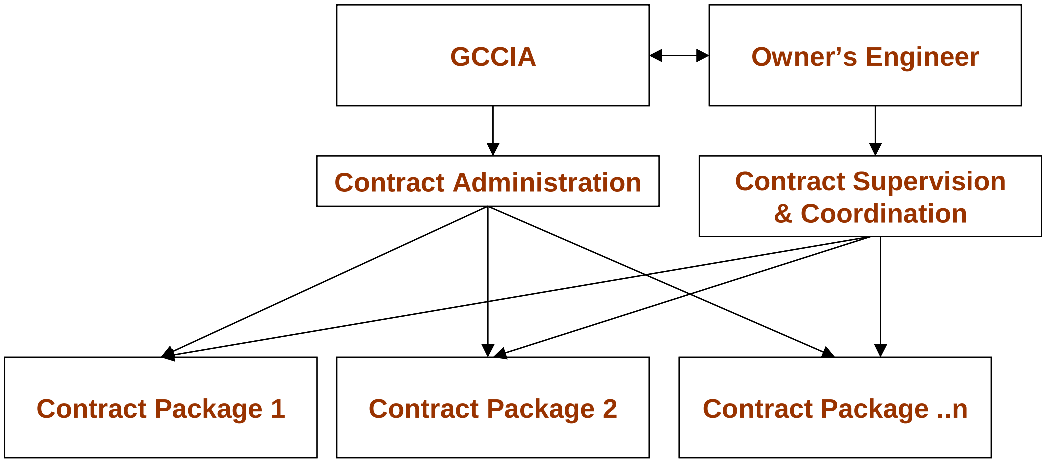

FIGURE 4. IMPLEMENTATION STRATEGY – FUNCTIONAL RELATIONSHIPS

Invitations to tender were issued by the Engineer. Tender documents were based on FIDIC Conditions for Plant and Design Build.

For the GIS substations only the original GIS manufacturers were pre-qualified for the tendering process. Of the seven companies pre-qualified, five presented tenders for either all or some of the GIS substations.

For the back-to-back HVDC station, three tenders were received.

For the transmission line lots, twenty three companies or joint ventures were pre-qualified. Of these, nineteen presented tenders (either as pre-qualified, or jointly with others).

For, the submarine and land cables, three tenders were received.

For the Control Centre, protection & SCADA and telecommunication system, four tenders were received.

The tenders were evaluated for technical conformance to the specifications and then a commercial evaluation was performed. During the tender evaluation process, numerous requests for clarifications were sent to the Tenderers to complete the information of their Tender. When Tenders included deviations to the requirements, either explicitly or implicitly they were systematically requested to withdraw any discrepancy at no extra cost. If not withdrawn, minor departures were penalized through equalization factors, whereas major deviations led to rejection of the Tenders.

The lowest evaluated Tenders, taking into consideration combination discounts, were then recommended for award of contract. The results of this evaluation process were as follows:

TABLE 2. RESULTS OF THE EVALUATION PROCESS

Description	Tenderer	Price M$US
Six (6) GIS Substations	ABB	222
Back-to-Back HVDC Converter	Areva-Cogelex	206
Overhead Transmission Lines: B1 – Al-Zour – Fadhili B2 – Al-Fadhili – Ghunan B3 – Ghunan-Salwa & Ghunan – Ras Al Qurayyah B4 – Salwa to Doha	Natrional Contracting Co HEC – MEEDCo HEC – MEEDCO National Contracting Co	95 40 107 38
Submarine and Land Cable	Prysmian/Nexans	343
Control Centre, Protection & Telecommunication	Areva/Cogelex	28
Total		1079

The six GIS substations were awarded to ABB. The back-to-back HVDC facility was awarded to Areva-Cogelex. National Contracting Company was awarded the two overhead transmission line packages (Al Zour to Fadhili and Salwa to Doha) straddling the borders Kuwait/Saudi Arabia and Saudi Arabia/Qatar. HEC-MEEDCO was awarded two overhead transmission line packages in Saudi Arabia (Al Fadhili to Ghunan and Ghunan to Salwa & Ghunan to Ras Al Qurayyah). The submarine and land cable from Saudi Arabia to Bahrain (Ras Al Qurayyah to Al Jasra) was awarded to Prysmian/Nexans. The Control Centre, protection and telecommunication package was awarded to Areva-Cogelex. The overall supervision of the Project, and to act as Owner's Engineer, to assist the GCC Interconnection Authority, was awarded to SNC-Lavalin.

In view of the proposal to package the project into several discrete contracts GCCIA's Engineer will have to carry out the following critical duties:

- Ensure the contract limits and interfaces are well specified.
- Ensure that the documentation of the contractors are consistent and cross referenced.
- Supervise the testing and commissioning of the individual substations as well as the interconnected systems.
- Supervise the individual contract schedules to assure meeting the overall project schedule.

- Facilitate the coordination between the individual contractors and the GCC member utilities. In particular, ensure that the interfaces at the GCC member ‘s interface stations and the data transfer necessary at those points are correctly engineered and implemented.
- Establish the overall control philosophy for the joint operation of the interconnected networks.

IV. PROGRESS ON IMPLEMENTATION

A description of the packages and the progress to date on the implementation is given below:

A. GIS Substations

Al Zour substation (Kuwait) consists of 400 kV GIS complete with three 650 MVA power auto-transformers 400/275 kV to interconnect the GCCIA network with the existing Al Zour 275 kV GIS Substation. Issues that had to be resolved were related to interfacing with the existing substation the exact location of the new GCCIA substation and the permits required to confirm the land use.

Al Fadhili substation (in Saudi Arabia) is a 400 kV GIS switching substation, which will interconnect Al Zour and Ghunan, as well as feed the 50Hz side of the HVDC back-to-back frequency converters. The 60Hz side of these converters will be connected to the existing Al Fadhili 380kV GIS substation. Issues that had to be resolved were related to the interfacing with the existing substation.

Ghunan substation (KSA) is a 400 kV GIS switching substation, that will connect Al Fadhili, to Salwa and to Al-Jasra substations.

Salwa substation (Saudi Arabia) is a 400 kV GIS intermediate switching substation between Ghunan (Saudi Arabia) and Doha South (Qatar) substations. This substation will further interconnect the transmission to Ghuwaifat (UAE) in Phase III of GCCIA interconnection project in the future. It was decided to equip the GIS substation for the future extension as part of Phase I.

Doha South substation (Qatar) consists of 400 kV-GIS with three 400 MVA power autotransformers, 400/220 kV to interconnect the GCC network with the existing Doha South 220 kV substation. Issues that had to be resolved were related to the interfacing with the existing substation and to adapt the design to the limited amount of space available.

Al Jasra substation (Bahrain) is a 400 kV GIS substation complete with three 325 MVA power autotransformers, 400/220 kV that will interconnect the GCCIA network with the existing Al Jasra 220 kV GIS substation.

B. HVDC Back-to-Back Converter Facility

The basic objective of the converter facility is to allow reserve sharing between the electrical power systems of participating member states (systems at 50 Hz and 60 Hz) and, as a secondary objective, to permit power transfer between the member states where such transfer has economic benefits.

To achieve effective reserve sharing it has been shown that up to 1200MW of active power will be able to be transferred from 50Hz to 60Hz systems and vice versa with sufficient speed of response and accuracy of control to stabilize the interconnected systems following the established critical loss of generation event within either system.

Provided that the ability to effectively share reserve is not compromised, the converter facility shall also allow economic interchange of up to 1200MW of active power between the systems in either direction.

In order to ensure the availability of 1200MW of inter-system real power transfer capability, three independent 600MW back to back converters will be installed.

Work is progressing on the detailed design studies for insulation coordination; HVDC converters reactive power capacity; converter transformer design; network harmonic impedance calculation and filter design. An issue was obtaining the necessary network data from the utilities.

C. Overhead Transmission Lines

The 400 kV overhead lines will be on double circuit towers with two (2) optical ground wires (OPGW). Each phase will consist of four (4) conductor bundles and the number of insulators was chosen to assure satisfactory performance in the prevailing environmental conditions.

The first section of the overhead transmission line is located in two different countries: Kuwait and Saudi Arabia. From the existing generation station at Al Zour in Kuwait, the transmission line will go to Al Fadhili in Saudi Arabia, a distance of 310 km (about 62 km are in Kuwait).

From Al Fadhili, the overhead transmission line will depart southward to Ghunan a distance of 112 km.

From the Ghunan substation, the overhead transmission line will depart southward to link with the Qatar network near the Salwa substation. The estimated distance from Ghunan to Salwa is approximately 255 km.

From the Salwa substation, the overhead transmission line will depart towards the Doha South Super substation in Qatar. The estimated distance from the Salwa substation to Doha South is about 97 km. From the substation located at Ghunan, there is also an overhead transmission line to Ras Al Qurrayyah at the gulf shore, a distance of about 36 km, where it will connect to the submarine cables to Bahrain.

Given the prevailing environment (line close to the sea coast and in desert conditions) it was decided to coat the insulators with silicone and to remove the envisaged built in line washing facilities. This should reduce the operation and maintenance costs. Special attention also has to be paid to the concrete mix for the foundations because of the presence of a high salt content in the soil (Sabkha). The transmission line routes have been surveyed and the design is being finalized. Figure 5 shows a tower being tested.

FIGURE 5. TOWER TESTING SITE

D. Submarine Cables

The system includes two (2) 400kV alternating current cables (2 groups of 6 cables) and related ancillary equipment that shall be capable of reliably transmitting 650 MVA of electrical power from an overhead line outdoor termination (pot-head) at a coastal substation at Ras Al Qurrayah in Saudi Arabia to an SF_6 termination at the Al Jasra 400 kV substation in Bahrain. The cables will be Oil-filled (SCFF) and the operating frequency is 50 Hz. The cable systems will require the construction of approximately forty-one (41) km of submarine cables (armoured) and approximately nine (9) km of underground cable (non-armoured).

Two (2) fibre optic cables will be installed which will be utilized for communication purposes in connection with the protective relaying, controls and monitoring equipment.

A detailed survey of the submarine and land cable routes has been completed. Figure 6 shows the survey vessel used to carry out the submarine cable route survey.

FIGURE 6. SUBMARINE SURVEY VESSEL

E. Control, Protection, SCADA and Telecommunication:

The system of Control, Protection, SCADA and Telecommunication for the GCCIA will form part of a single work package in order to provide compatible equipment and systems for the whole GCCIA 400 kV interconnection network. Equipment will be implemented in all substations of the project namely, Al-Zour, Fadhili, Ghunan, Salwa, Ras al Qurrayah, Al-Jasra and Doha South. This work package will also include the supply and installation of a new GCCIA Interconnection Control Center (ICC) SCADA/EMS system which will be located at the site of the new Ghunan substation. The IEC 61850 protocol will be used for the communication.

V. PROJECT SCHEDULE

The update of the technical and economic feasibility of the Project was completed in early 2004. Approval for the method of financing of the Project was received in May 2004. In early 2005 Tender documents were issued to contractors pre-qualified for the different work packages. Tenders were received in June 2005 and contracts were awarded for project execution in November 2005. The Project should be in operation by early 2009.

VI. OTHER GCCIA ACTIVITIES

The other activities being carried out are the Management Consultancy mandate to define the organization of the GCCIA and to prepare the Authority for the Operations and Trading phases. A mandate has also been given to develop the Legal Framework which will govern the ownership and operations of the interconnection. Interconnection agreements for Energy Trading and Reserved Sharing will be prepared.

VII. CONCLUSIONS

This Project has been under study since the mid-eighties and involved the agreement and participation of six GCC countries. The process from study to implementation was a fairly protracted one as it involved: demonstrating the technical and economic feasibility; agreements between the countries; creation of the GCC Interconnection Authority; agreements on cost sharing and financing of the Project. All these hurdles were overcome and the Project is finally being implemented. The implementation strategy adopted was to divide the Project into work packages and to go out for International Competitive Bidding. There was a large response to the request for Tenders and the GCCIA was able to get competitive prices for the various packages. Contracts have been awarded and work is in progress on the detailed designs by the Contractors. The design review process by the Engineer is well underway. Site preparation work has now commenced and the Project is targeted to be completed on schedule.

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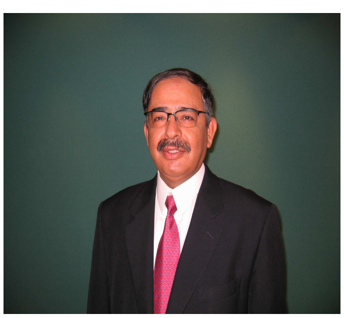

Adnan Al-Mohaisen graduated from King Saud University in Riyadh, Saudi Arabia in 1976 with a bachelors degree in Electrical Engineering. Upon graduation he was among the first to be hired in the Royal Commission for Jubail & Yanbu. Thereon, he worked in various positions and in 1980 managed to attain, by scholarship, a Masters degree in Electrical Engineering (Power Systems) from the University of Missouri in 1981. During the 29 years that he was with the Royal Commission for Jubail & Yanbu, Adnan held 3 senior positions of Deputy Director General in the Planning & Projects, Community Services and Public Services areas. In late 2004, Adnan was nominated to become General Manager for the GCC Interconnection Authority in which he took the position in January 2005. Adnan also headed and participated in various committees in the Royal Commission and other public organizations. Adnan has also participated in management and career development courses from various reputable universities, such as the University of Chicago and the University of Southern California and the University of New South Wales in Australia.

Luc Chaussé graduated from École Polytechnique de Montréal, Québec, Canada in 1974 with a Bachelor Degree in Electrical Engineering. He is the Project Manager for the GCC Interconnection Project. During the 32 years of his career, he has been involved with manufacturers, contractors and consultants in transmission network projects as well as in thermal nuclear and gas turbine projects in Canada and overseas. He has developed a solid basis in the technical design of the electrical facilities namely with respect to automation, SCADA, protection, HV apparatus and telecommunication. He has been leading various major projects and managing turnkey contracts on both the client's and the contractor's sides. He has an extensive experience overseas with projects in Middle East, Africa and South America where he spent many years as an expatriate for on-site supervision of works. He is a member of the Order of Engineers of Québec and of the Institute of Electrical and Electric Engineers.

Satish Sud graduated with a B.Tech. (Honours) in Electrical Engineering from the Indian Institute of Technology, Kharagpur, India and obtained his M.Sc. in Engineering from the University of Manitoba, Winnipeg, Canada. He is Vice President in the Transmission and Distribution Division of SNC-Lavalin. He is an electrical engineer with over 36 years of experience and is responsible for the development and management of the Power Systems Group which undertakes electrical transmission and distribution projects, electrical system and energy studies, master plans, power sector reform and restructuring studies, and economic and financial studies. He has directed numerous electrical generation, transmission planning and system design studies, both in Canada and overseas. He was the project manager for the planning studies to determine the techno-economic feasibility of various interconnection projects where both AC and DC alternatives were considered. He has also developed master plans for electrification and national energy plans for several countries. Some of the countries in which he has participated in planning studies and/or projects are: Canada, USA, Honduras, El Salvador, Nicaragua, Panama, Guyana, Argentina, Peru, Senegal, Mauritania, Mali, Guinea, Ivory Coast, Cameroon, Niger, Nigeria, Benin, Togo, Rwanda, Tanzania, Botswana, Zambia, Zimbabwe, Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates, Oman, Iraq, China, India, Philippines, Indonesia, Vietnam and nine countries of south eastern Europe. He is a member of the Order of Engineers of Quebec, Institute of Electrical an Electronic Engineers and the Institution of Engineering and Technology (Fellow).

Received January 15

5. PLANNING THE EASTERN POWER CORRIDOR OF SOUTHERN AFRICA (PAPER 07GM0743).

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Lawrence Musaba, *Southern African Power Pool, Zimbabwe*
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Mark Dingle, *Eskom, South Africa*

Abstract--This power corridor will link the thermal stations situated on the coalfields of South Africa, to the hydroelectric powers stations in the Zambezi River (Cahora Bassa and Mphanda Nkuwa). Loads will be at Edwaleni in Swaziland, Maputo and Beira in Mozambique, Blantyre and Lilongwe in Malawi, Madagascar, Dar es Salaam in Tanzania and onwards towards Uganda and Kenya.
The eastern corridor of Southern Africa has hydro, gas and thermal energy sources in particular in Mozambique. Emanating from the South African National Grid thermal power stations, two 400kV transmission lines connect the port City of Maputo and the Swaziland Edwaleni substation to form the first part of the proposed Eastern Corridor. This is with the joint venture company, Motraco. From Maputo, the lines can run northwards to the port city of Beira and then onto Cahora Bassa hydroelectric power station connecting on the way the proposed gas thermal station in Temane. Cahora Bassa supplies Zimbabwe, Mozambique and South Africa and a planned Malawi connection. This power station has the potential for expansion at the North Bank. Lower downstream, another power station, Mphanda Nkuwa is proposed. Close to Mphanda Nkuwa, there is the potential of building a thermal station based on coalfield in Moatize. Interconnecting these power stations will provide a very strong base for further extensions northwards to Dar-es-Salaam and with a DC tee–off to Madagascar. Madagascar is an island load off continental Africa. At Dar Es Salaam, opportunities exist for further extensions northwards towards Uganda and Kenya. In addition to the thermal and hydro energy sources, gas could also enter the power generation sector. At present, gas in Mozambique is imported by the Sasol Plant, in South Africa, as primary feedstock into the coal to gas to liquid petroleum conversion process.

***Index Terms*—**Power corridor, power pool, power system integration, power system development, electricity investment.

I. NOMENCLATURE

HVDC - High Voltage Direct Current
EAC - East African Community
NEPAD - New Partnership for Africa's Development
SADC - Southern African Development Community
SAPP - Southern African Power Pool
CCGT - Combined Cycle Gas Turbine
EASTCOR - Proposed interconnection of power networks

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Mark Dingle, Pr Tech. Eng is with Project Development Department, Eskom, Sandton, RSA (e-mail: mark.dingle@eskom.co.za).

Fig. 1. **The envisaged EASTCOR Inter-connector connecting loads and generation along the African East Coast**

II. INTRODUCTION

In Africa access to modern energy services remains very low. Less than 20% of Africa's population has access to electricity and for them power rationing and cuts are part of the daily routine. This inhibits job creation, industrial investment and entrepreneurial development, and impedes production of competitive goods and services [1]. Wider use of modern, sustainable and affordable energy services will improve the efficiency of health and education services, reduce deforestation and ease the daily burden that women bear in Africa. Joint ventures in the power industry will assist to create the investor confidence necessary to change the energy generation and supply situation within the eastern region of Africa.
The energy needs of the southern and eastern region of Africa are great, even more generation and transmission capacity is needed if the growth targets of the governments of the southern and eastern region are to be attained. The required capital investment in infrastructure is enormous.

- Fig. 2 illustrates Eskom must commission of at lest 1000MW per annum for the next ten years, this increases if growth targets are attained [2]

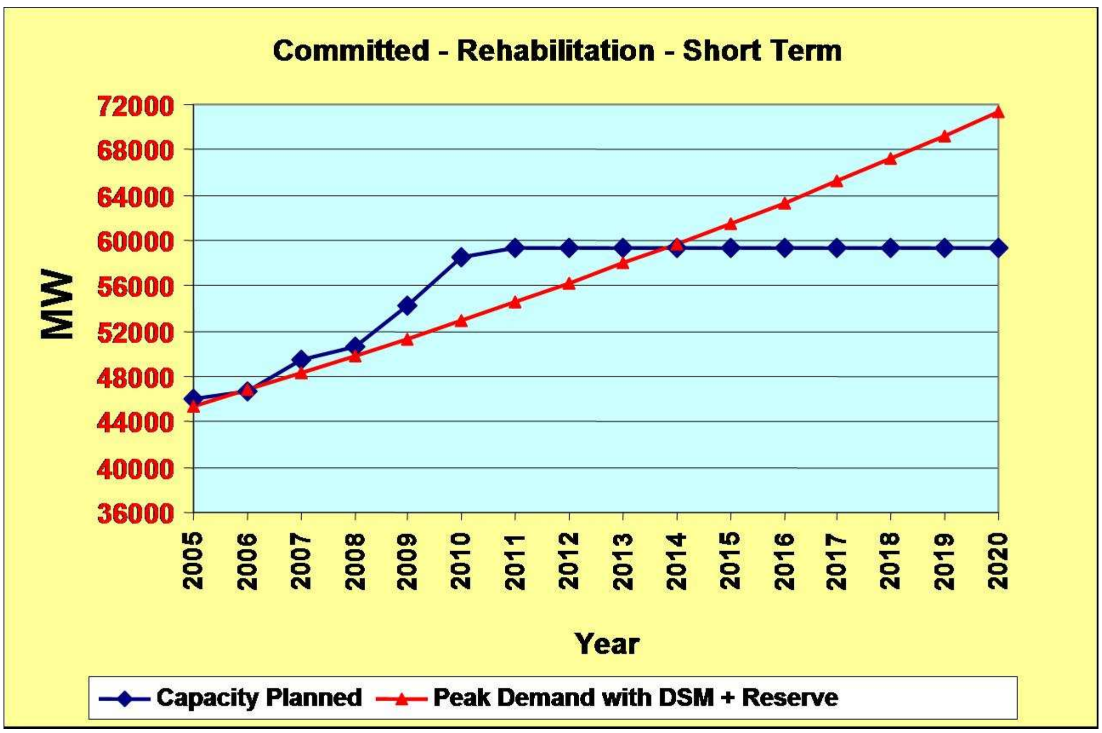


Fig. 2. Growing demand for electricity in the SADC Region [2]

- EAC must spend USD 8,25 billion should high growth scenario occur
- A transformation in EAC economy requires expenditure of USD 16 billion on energy projects
- The EAC region needs to commit to creating 1025MW additional capacity by 2015
- The EAC region has already run out of surplus capacity with no reserve margin as depicted in Table 1
- Mozambique has potential at Mphanda Nkuwa at 1300MW costing USD2.3 billion, Baroma, Cahora Bassa North Bank, Temane Gas and Moatize Coal Fired generation opportunities
- The transmission costs are exorbitant and detract from the generation business cases and as such need to be separately addressed, hence the need for EASTCOR

- If energy can be delivered to the region at ±US 3,0c it becomes feasible to explore the import energy [3].

It is against this background that the formation of a joint venture generation and transmission vehicle is proposed to address the challenges facing the regions' electricity industry.

III. REGIONAL ENERGY SITUATION

A. Power Development Activity

The SAPP convened the Regional Electricity Investment Conference in Windhoek, Namibia in September 2005 to highlight the region's need for investment in electricity projects. To date the major generation projects (>500MW) under construction are limited to South African pumped storage, thermal station rehabilitation and new coal builds. Much activity is devoted to the development of Westcor, Kudu CCGT and Mphanda **Nkuwa** hydro-electric scheme in the region.

B. Natural Resource Distribution in the Region

Not all the east coast countries of Africa have the abundant natural resources of their west coast counterparts such as the hydro, gas and oil of the Democratic Republic of Congo and Angola or the coalfields of South Africa, Botswana and Zimbabwe [4]. The countries mentioned lend themselves to sources of base load generation which may be transported to countries not so blessed with these energy sources via long transmission systems as illustrated in Fig. 3.

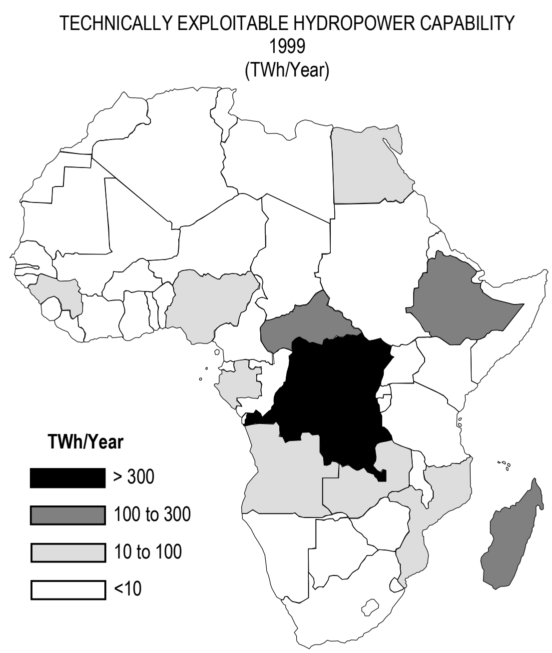


Fig. 3. The natural resources for bulk power generation do not exist in the East African region

C. Regional Environment and Clean Energy

Deforestation is a major concern to all authorities in Africa, it is only via the concerted efforts of governments and power utilities that a change to Africa's main fuel source may be brought about though the creation of distribution systems supplied by cheap energy sources. Fig. 4 is evidence that many Africans spend major portions of the time collecting fuel for heating and lighting leaving precious little time for education and recreation.

TABLE I
DEMAND AND CAPACITY IN THE REGION [3]

Country	Capacity Available	Estimated Demand	Current deficit or estimated year of deficit
Rwanda	46 MW[4] in 2002	58-61 MW[3] in 2002	12-15 MW
Burundi	28 MW[3] in 2002	36-38 MW[3] in 2002	8-10 MW
Uganda	285 MW[5] in 2004	350 MW[4] in 2004	65 MW
Tanzania	806 MW[2] in 2002	475 MW[2] in 2002	by 2005-2007
Kenya	1051 MW[4] in 2004	833 MW[4] in 2004	by 2005-2007
East-DRC	33 MW[6] in 2004	60 MW in 2004	27 MW

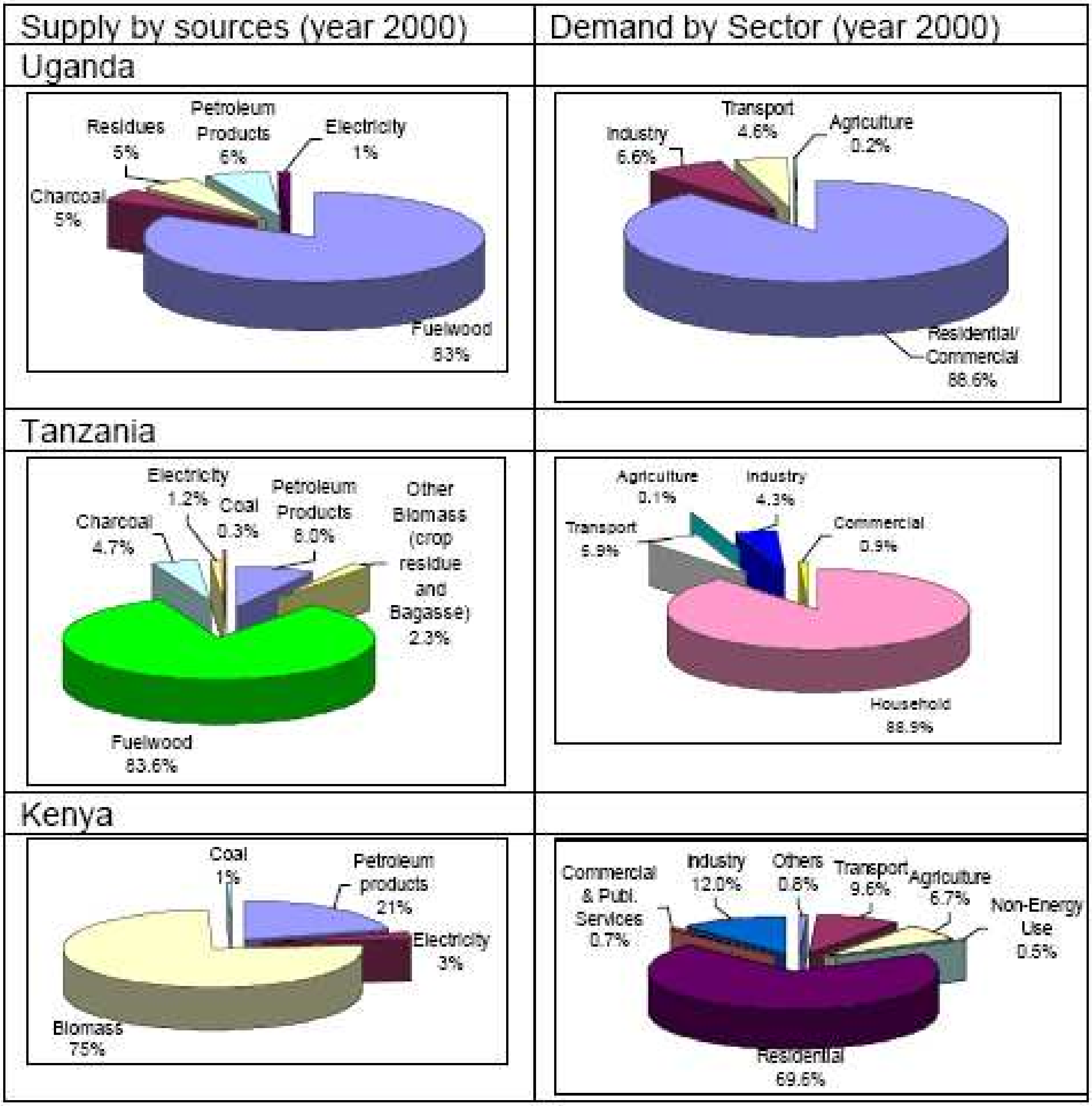
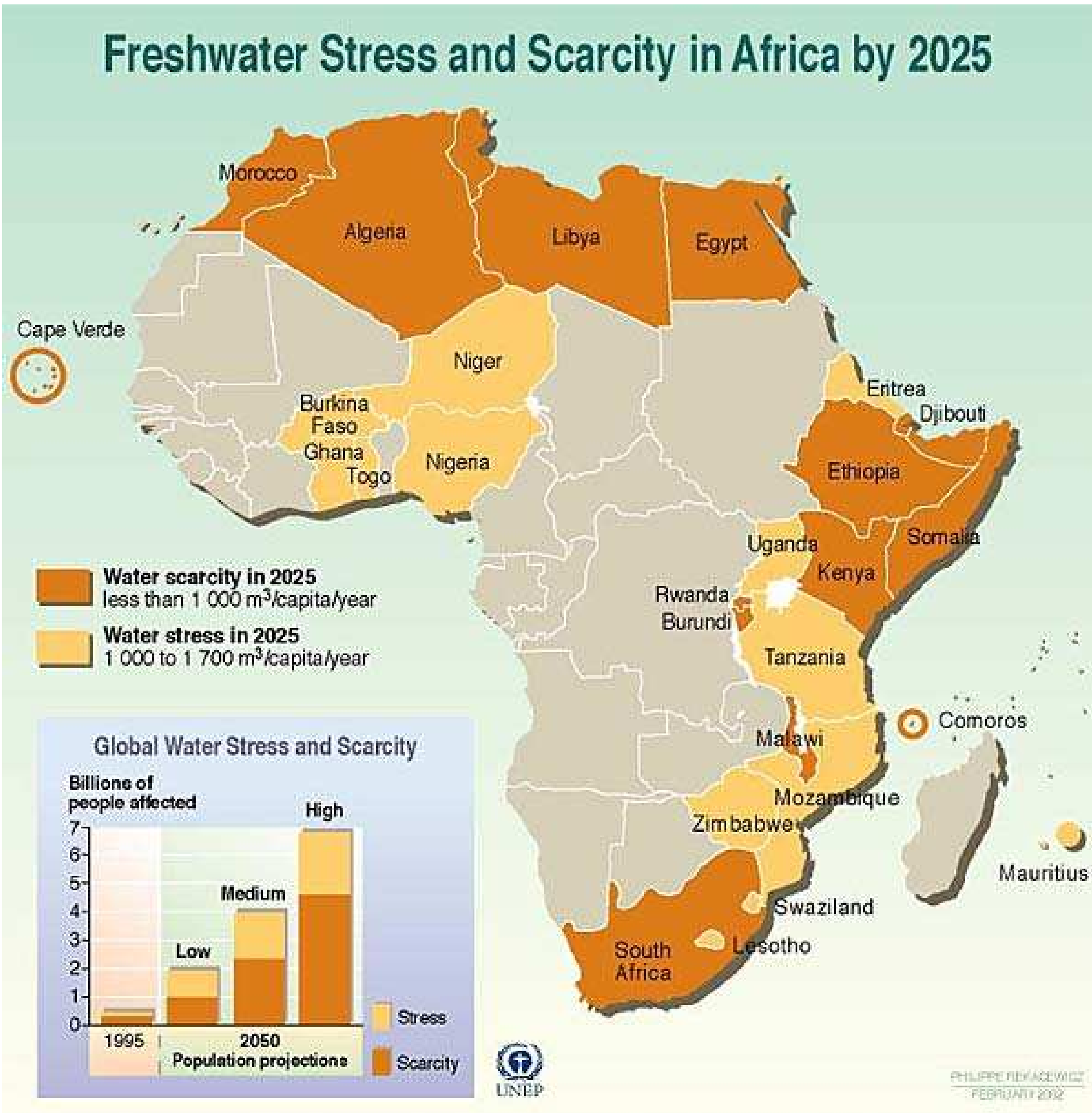


Fig. 4. The inhabitants of East Africa depend largely on biomass and wood fuel energy sources [3]

The impact of bush fires and emissions from thermal power stations contribute toward the global warming and remain a cause for concern, these emissions may be curtailed where clean, renewable energy may be generated at sources such as the Inga rapids, depicted in Fig.7 or the Zambezi River System [2]. The flared gas from the Angolan and other west African oil fields may be converted to electricity and transported to the southern and eastern countries via integrated transmission systems such as those proposed in this paper.

D. Southern and East African Climate

The eastern region is prone to dramatic climatic changes such as drought, as is currently being experienced this cyclic occurrence has a negative effect on utilities that are reliant on hydro electric plants to provide their base load requirements. Through the establishment of joint venture Independent Power Producer, Independent Transmission Operator companies the energy needs of the eastern African power utilities may be met by alternate generation sources. Further to the energy needs, water resources are highly politicised, particularly when, as in this region, these water resources occur along international boundaries and are utilised by more than two nations. Water courses provide sustenance to local inhabitants as well as contribute significantly to the agriculture industries of this part of Africa [5] [10]. Fig. 5 indicates the importance attached to dwindling water resources in the region.



Source: United Nations Economic Commission for Africa (UNECA), Addis Ababa; Global Environment Outlook 2000 (GEO), UNEP, Earthscan, London, 1999; Population Action International.

Fig. 5. An indication of water availability in the future [5] [10]

E. *Foreign Direct Investment*

Investor confidence is low throughout the region which negatively impacts the realisation of mega-power generation projects. The long term nature of the projects coupled with the perceived high risk and the absence of anchor bulk users brought upon by high or subsidised electricity tariffs create a spiralling effect discouraging investment within the region. International joint ventures which have the support of national governments orchestrated under the auspices of regional organisations such as SADC, COMESA and NEPAD with links to continental institutions such as the African Union have the ability to attract investors if properly constituted.

IV. TOWARD A REGIONALLY INTEGRATED NETWORK

A. *Diminishing Surplus Generation Capacity*

Growth in the African regional economies has resulted in a shortage of generation into the future as many of the planned generation projects have not materialised. The attention of the major world economies has shifted to meeting their own needs in the Americas and the Far East where expansion programs exceed our own (smaller) needs. It is against this present insatiable demand for power plants that Africa must compete for funding, construction and operational expertise [11]. Fig. 6 depicts the growing EAC economies and the consequent increase in peak energy demand.

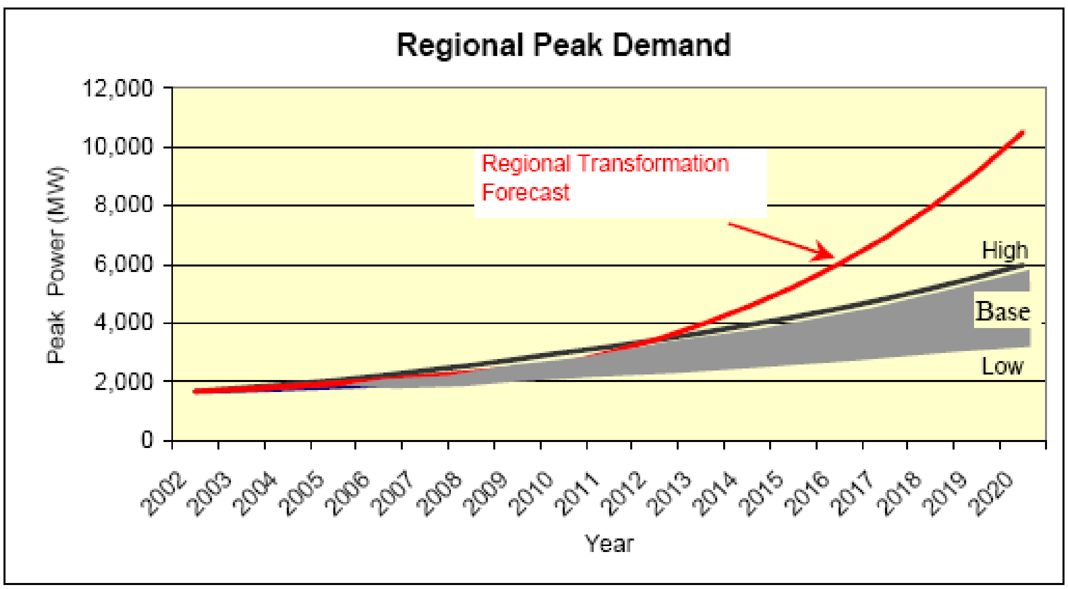


Fig. 6. Predicted future peak demand in the East African Community [3]

B. *Need for Financing*

To quickly resolve the looming energy crisis, the regions administrators must become innovative in their quest for project financing. This means they need to make a call on the successful partnerships and structures that have worked in the past. The need to provide comfort to the prospective financing consortia must be one of the most important criteria in how a power system is structured, governed, technically and operationally implemented. The presence of one or more bulk, long term power offtaker /s is an essential component of the financing. The development of a securitised Power Purchase Agreement (PPA) is a critical component of the financing package, partners to these agreements must be under development during the same time frame as the technical studies.

C. Governance and Regulation

Good governance and sound regulatory policies encourage and attract developers of large projects [11]. To influence regulatory change for the benefit of the electricity industry a powerful lobby group is required that is clear in it's objectives to encourage meaningful change for the benefit of generation, transmission and distribution sectors. The lobby group obtains it's authority by virtue of the development and investment prospects it brings to the region. The joint venture is such a group whose purpose is to incubate new, clean and renewable energy sources by providing a bulk market. The joint venture vehicle pulls together multiple activities at a multitude of national sites, provides the good governance and in doing so creates the clarity and security which ultimately leads to easier access to grant funding that supports the development studies needed to bring a venture to fruition.

D. Embracing the Many Stakeholders

The state of the electricity supply in the region and the importance attached thereto may be measured by the number of stakeholders that are involved in investigation, research and fundraising efforts. Amongst these are the SAPP with their Long Term Expansion Plan investigation, SADC with the Regional Indicative Strategic Development Plan (RISDP), NEPAD with the Short Term Action Plan (STAP), the EAC with the East Africa Power Master Plan (EAPMP) and the Nile Basin Initiative with the Nile Equatorial Lakes Subsidiary Action Program (NELSAP). Organisations such as the World Bank provide support in some cases; The Southern Africa Power Market Program is one such example.

E. Alignment with Regional Priorities

The region has many priorities associated with the creation of infrastructure, promotion of development opportunities [7], communications enablers, the relentless fight against poverty and HIV/AIDS. The linking of Africa's power pools as shown in Fig. 7 will enable those with abundance to share with those communities with shortages.

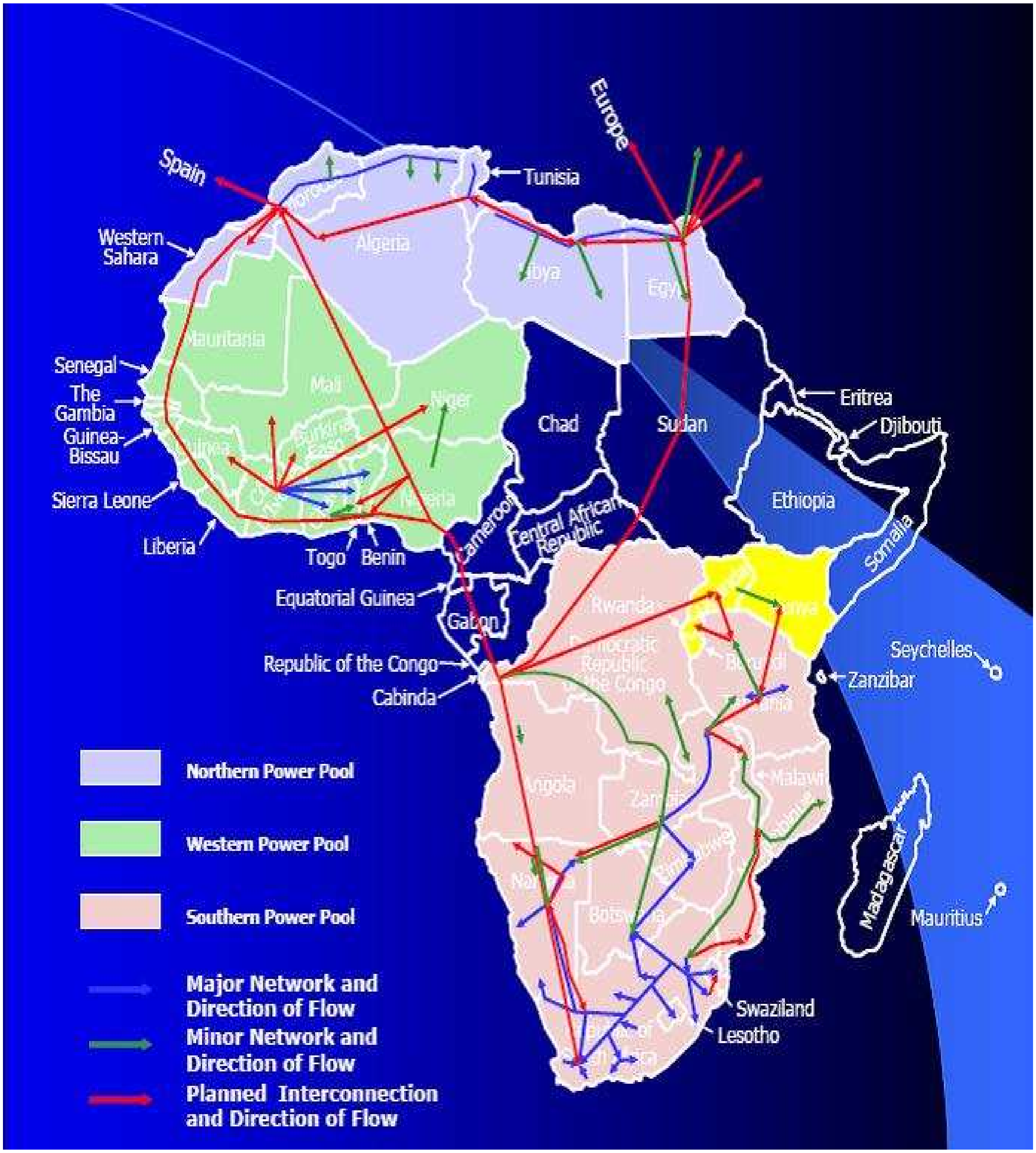


Fig. 7. Grande Inga will supply EAC countries

The establishment of reliable, affordable and accessible power sources is just such a priority where the trend of the diminishing generation capacity must be reversed whilst ensuring reserve margins are sustained. Other priorities include the establishment of North – South interconnection in Mozambique which will enable the delivery of power generated in North to the load centre in South. The interconnection of member states such as Malawi and Tanzania to the regional grid, not forgetting the needs to integrate the power systems of Rwanda, Burundi, Eastern DRC to the EAC Grid is one of priority. As membership of SADC grows, the new member countries should be empowered to share in the benefits of power pool operations, such a case as the newly admitted SADC member, Madagascar's interconnection to the SAPP grid must be investigated.

F. Existing Studies

Much innovative work and many power system studies have been performed. This good work requires consolidation and packaging into a program acceptable to the investors. The creation of a joint venture company, suitably mandated may commission the integration studies so desperately required to complete this consolidation. Valuable studies exist from Acres (now Hatchenergy), SNC•Lavalin, HydroQuebec, Black & Veacth, SwedPower and Norconsult to name just a few. These studies provide the basis from which the joint venture company may initiate it's research and provide important information as to how the final scope of the initiative might be formed.

G. Success Stories

The region has implemented a number of successful initiatives within the energy sector. The pioneer is Cahora Bassa power plant (2075MW), being one of the first IPP in Africa. Other examples include the privatisation of the power division of Zambia Consolidated Copper Mines into Copperbelt Energy Corporation (CEC). CEC is now an Independent Transmission Operator (ITO) and an IPP with it's own peaking plant and subsidiary telecommunications company known as CopperNet.
Fig. 8 illustrates another ITO, Motraco, a joint venture between the power utilities of South Africa, Swaziland and Mozambique. Motraco successfully transports power from Eskom's generation plants across three countries in southern Africa to supply the MOZAL aluminium smelter in the city of Maputo.

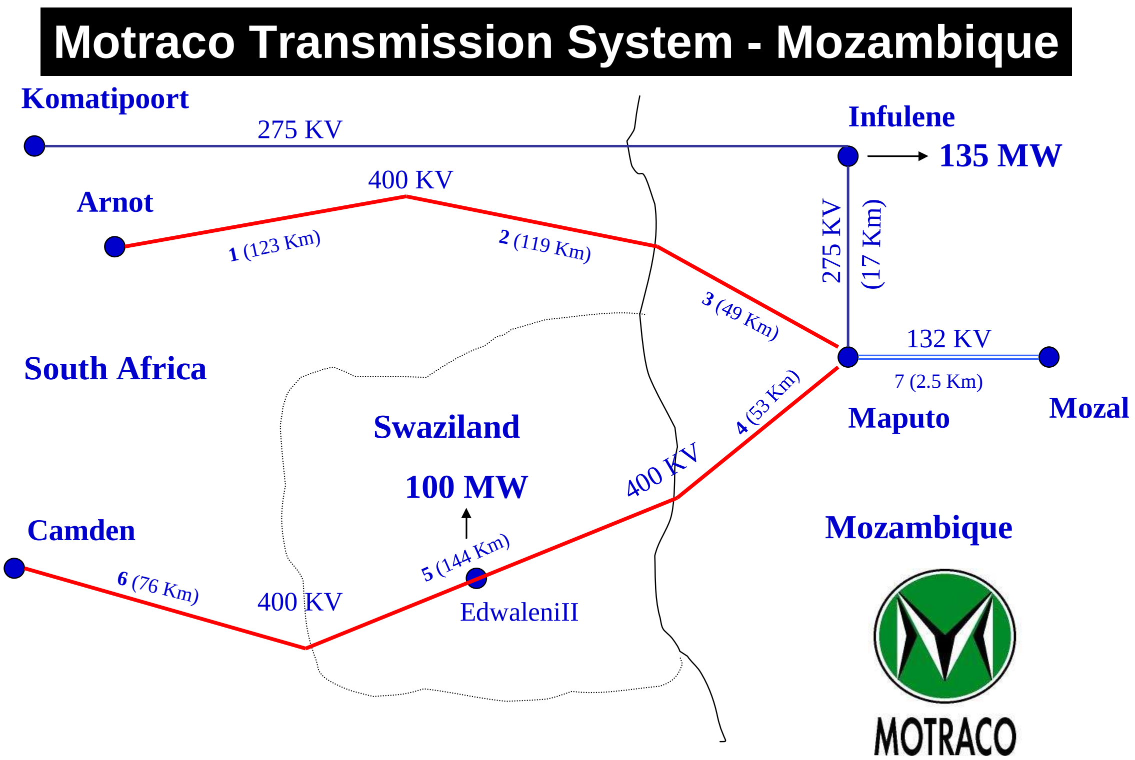


Fig. 8. An example of a successful joint venture in the region

The formation of the southern region's power pool in 1995 has been a tremendous success in a partnership between the power utilities of SAPP with the Co-ordination Centre based in Harare and operating within the ambit of the Southern African Development Community.

V. THE PLAN OF ACTION

As with any major initiative, planning, negotiation and conclusion of agreements, lobbying of industrialists and financiers is a time consuming process. The EASTCOR Inter-connector must be approached in phases to allow for the consolidation of plans, establishment of generation sources and the phased roll-out of the transmission system as well as the infrastructure required to integrate the system into local utility networks.

A. A Phased Approach

Each utility within the region has mapped out it's generation and transmission expansion plan, these plans must be allowed to reach fruition to meet the immediate demands of the national customers. Many of the larger expansion projects will dovetail with an integrated grid plan and may be included as part of the funding drive, thus providing a measure of local independence and augmenting power system stability.

B. Phase I (South Africa - Mozambique - Malawi)

Several large generation and transmission projects within the Zambezi River basin have reached an advanced stage [9]. These projects when integrated provide a capacity in excess of 5000MW in northern Mozambique as depicted in Fig. 9.

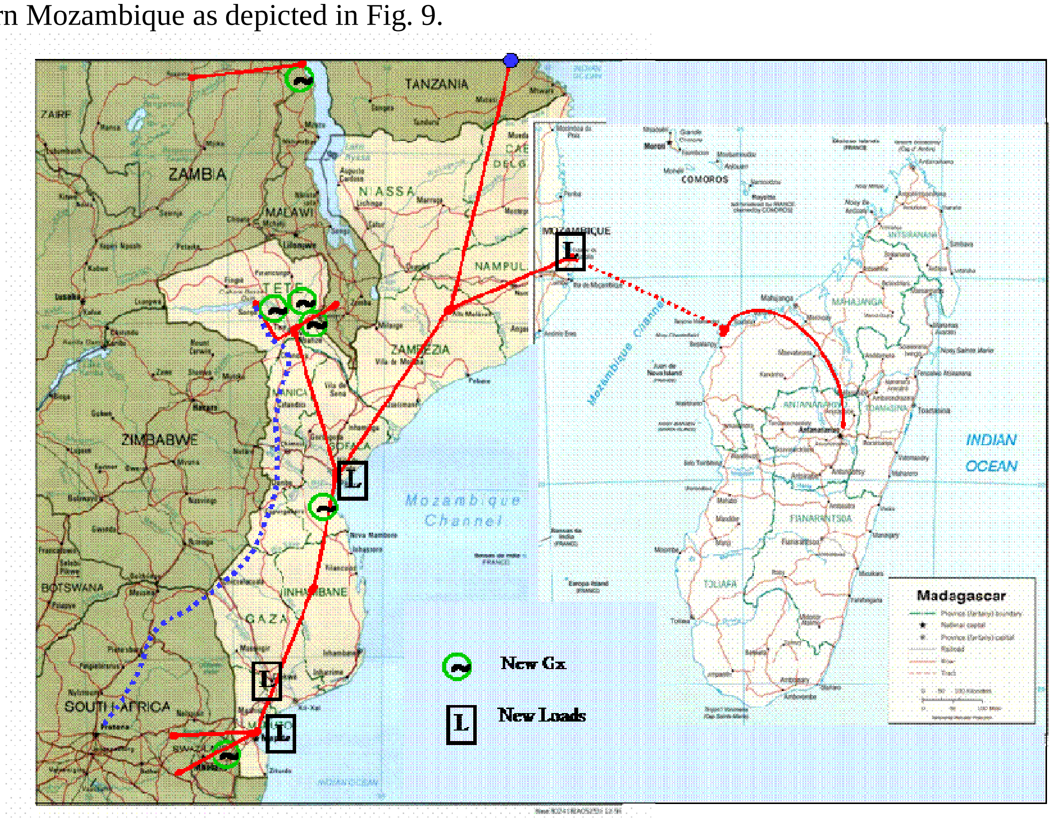


Fig. 9. The connection of abundant hydro, coal and gas generation sources to remote markets from Mozambique

The transmission inter-connector (Matambo – Phombeya 220kV) to Malawi has been planned and PPA negotiations are to be concluded soon. The establishment of a national grid in Mozambique has been planned and the upgrading to 600kV and increase in the capacity of the Songo – Apollo 533kV High Voltage Direct Current transmission system is under development. This situation creates both generation capacity and the ability to transport power to the markets of the east and south. A number of industrial developments have been earmarked for this area and Fig. 10 illustrates the Nacala Development Corridor as an example.

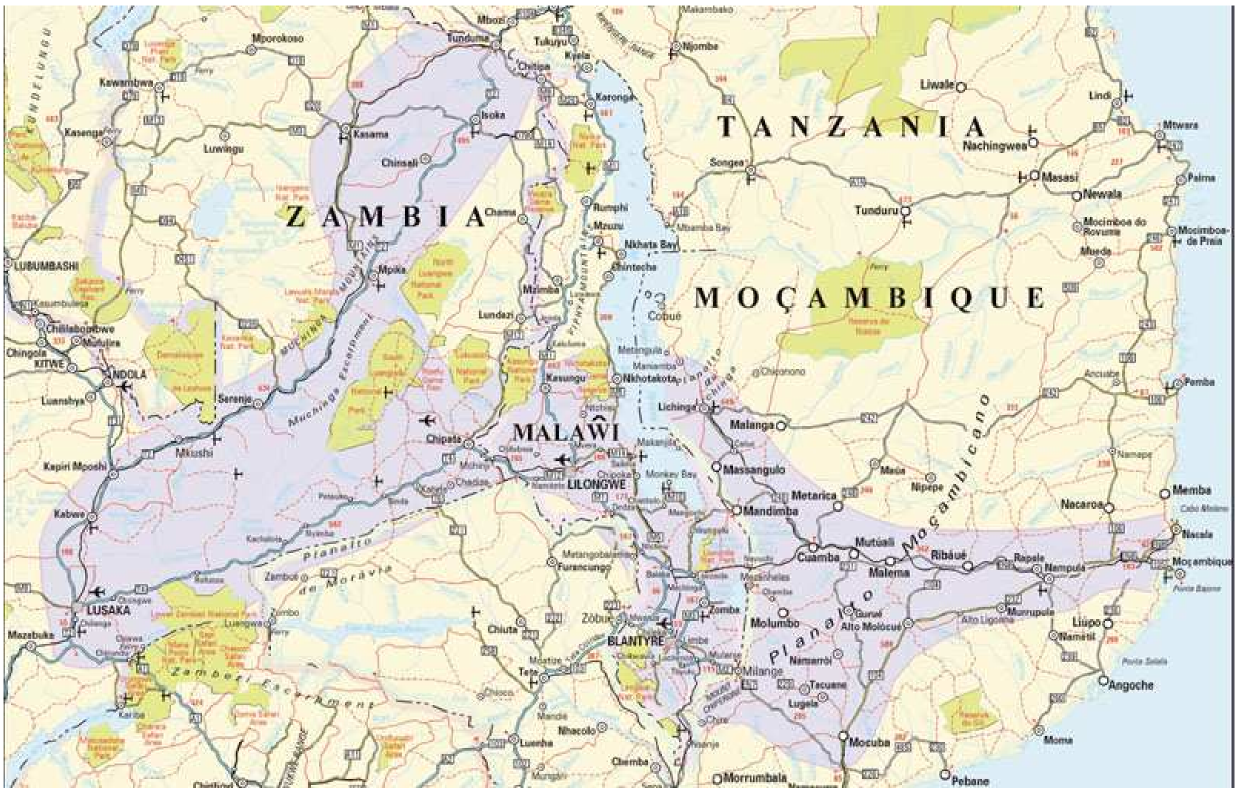


Fig. 10. Many development corridors have been defined or established, the Nacala Corridor is one such initiative

C. Phase II (Tanzania – Rwanda – Burundi)

The load in Tanzania will reach 1390MW and in Rwanda and Burundi 195MW and 180MW respectively during the planning horizon. This region lends itself to interconnection of the abovementioned transmission grids as proposed in the NELSAP study [3]. Further to this the study identifies a number of generation opportunities in southern & eastern Tanzania and the northern Malawi region (viz. Stieglers Gorge 2100MW, Songwe 380MW, Muhuchuma Thermal 400MW). The region also lends itself to establishment of pumped storage schemes, the regions need for base load is thus temporarily met from the Zambezi pool whilst peaking capacity is provided by the many attractive hydro-electric opportunities as seen in Fig. 11. The region is further re-inforced and connected to southern markets via the planned TANZAM Inter-connector (Serenge – Mbeya 330kV).

Fig. 11. A vital part of EASTCOR must be the integration of local generation capacity onto the corridor

D. Phase III (Tanzania - Kenya – Uganda)

The Kenyan load increases to 2344MW whilst the load of neighbouring Uganda grows to 1140MW. Uganda currently supplies capacity to Kenya, however lake levels have dropped significantly and the regions' dependence on hydro electricity has highlighted the need to inter connect with other sources of generation. In this area the Arusha – Nairobi (Arusha - Embakasi 330kV) Inter-connector is planned between Tanzania and Kenya, the re-inforcement of the Kenya – Uganda (Tororo – Lessos 220kV) Inter-connector is also planned. A number of generation opportunities in the area should be considered during this phase (viz. Masindi 1020MW, Ayago North & South 580MW and Bujagali 250MW). Further opportunities for pumped storage and peaking capacity need to be considered. The Tanzania – Kenya interconnection is linked to Zambia – Tanzania Interconnection (TANZAM) mentioned earlier. This interconnection will ensure connection of the Tanzania grid into Zambian system which is linked to DRC grid with an enormous potential at Inga site.

E. Phase IV (Uganda – Eastern DRC – Inga)

This phase will conclude the regional integration where eastern African countries share the benefits of abundant low cost energy generated by their west coast neighbours. It has been proposed that an Inga – Kenya HVDC inter-connector would be required in the future. Such a transmission system not only benefits the eastern coast countries but using multi-terminal HVDC configuration reliable, affordable energy is brought to the Kisangani area of north – eastern DRC. A connection of this magnitude allows the development of Wanie Rukula 690MW and Kisangani 460MW generation stations by providing access to markets for the capacity [3]. This phase remains a significant challenge both logistically, due to the long distances through equatorial forest and economically with the development of Grande Inga, as significant tariff changes might result.

F. The Joint Venture Company

Fig. 12 illustrates that by establishing a multi-national joint venture company, opportunities arise that are not normally available to a single shareholder national based company. Investors take comfort from governance structures and the close association with the regional community organisations such as COMESA and SADC. Although joint ventures are difficult to create due to the complex agreements necessary the successes that have been forthcoming bear witness to their merits and should be investigated. EASTCOR, if successfully constituted will become a vehicle to create sustainable development in the region, complimenting the efforts of local authorities and utilities and bringing a measure of power system stability to the region. Infrastructure and industrial developers will take comfort that firm supplies are available to meet their energy needs.

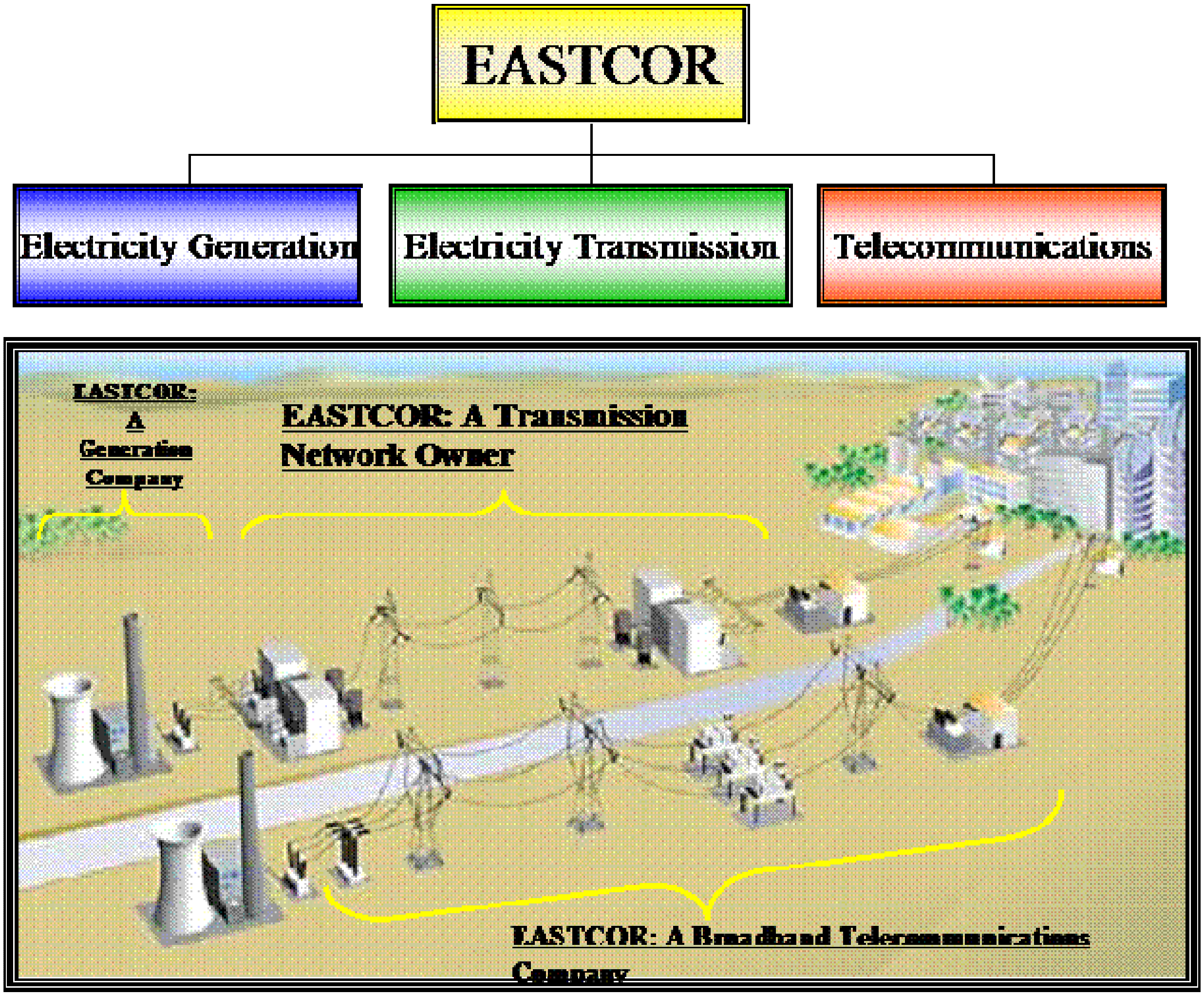


Fig. 12. The joint venture company has three distinct lines of business, all of which are desperately needed for the region's success into the future

VI. CONCLUSION

Power pooling in the southern region has been successfully implemented over the last ten years. Pool members have supported one another during their different times of difficulty; numerous challenges face the region's power utilities. The cyclic droughts place huge demands on utilities dependent on hydro electric generation sources and raise the risk profile of establishing large industries such a smelter operation. Economies of scale dictate that larger pools of generation produce lower more stable tariffing, making it easier for developers to accurately predict their input costs over long periods. The southern and eastern region of Africa face demands from the inhabitants for faster electrification, many have initiated rural electrification programs which uplift living conditions and relieve the pressure on the natural environment. These programs are significantly burdened by utility efforts to create, fund, commission and operate large generation plants. By participating in joint venture operations such as an EASTCOR, their efforts may be focussed on the tremendous challenge of electrification.

VII. ACKNOWLEDGEMENT

The contributions made by the staff of the SAPP at the Co-ordination Centre in Harare are gratefully acknowledged. The research initiated by the Nile Basin Initiative and the sponsors of the NELSAP has contributed significantly to the concept of an Eastern Power Corridor.

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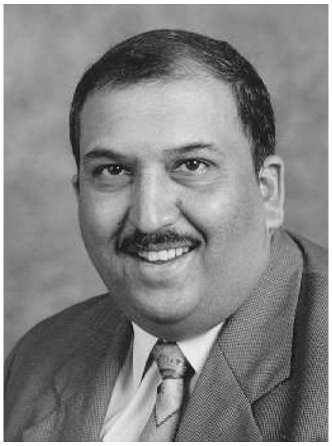
IX. BIOGRAPHY

Mark Dingle (Pr.Tech Eng) completed his training at the Post Office Telectronics Institute (POTELIN) during 1977. His experience includes the commissioning and maintenance of all of the various telecommunications technologies found in public, avionics and utility networks. Duties at Eskom included efforts to establish the Southern African Power Pool, negotiations toward the establishment of international ventures such as MOTRACO, recommissioning of Apollo – Cahora Bassa and the interconnection of the Eskom Grid with neighbouring utilities. Later, with Eskom Enterprises he evaluated business opportunities such as investments in foreign Telecom Operators such as CAMTEL and Kenya Telecom. Mark is a Senior Project Advisor in the Project Development Department of Enterprises Division.



Pathmanathan Naidoo (Pr.Eng). Senior General Manager in the Office of the Chief Executive of Eskom South Africa. Completed over two decades of engineering service to Eskom and now focussed on sourcing, lower cost, renewable, bulk electrical energy for continental consumption; to prepare the power generation and power transmission technologies in association with environmental and financial requirements so as to yield longer term sustainable business solutions.

Augusto de Sousa Fernando Senior Eng. In EDM the National Power Utility in Mozambique. He was full involved during the establishment of the SAPP Chairing the Telecommunications Working Group and recently the Management Committee. He also represented EDM during the study phase of MOTRACO project. In EDM he was managing the Operations and System Protections and later on he was nominated Transmission Director and his currently is Executive Director for Generation, Transmission and Market Operator. He is also a Vice-president of the Council of Engineers of Mozambique.

Lawrence Musaba graduated with a BEng degree with Distinction from the University of Zambia in 1989, an MSc degree in 1991 and a PhD in 1996, both from the University of Manchester Institute of Science and Technology (UMIST) in the UK. Dr. Musaba worked for Midlands Power International in Birmingham, UK, as Assistant Project Development Manager until September of 1998, when he was appointed Head of the Department of Electrical and Electronic Engineering at the University of Zambia. Dr. Musaba was appointed the Southern African Power Pool Co-ordination Centre Manager in February 2002. Dr. Musaba is a Chartered Electrical Engineer of the Institute of Electrical Engineers of the United Kingdom, a Member of the Engineering Institution of Zambia and also a Registered Engineer.

Received January 19 2007

6. ANALYSIS OF THE PERFORMANCE OF AN AFRICAN JOINT VENTURE COMPANY ESTABLISHED FOR THE TRANSPORT OF BULK POWER FROM ESKOM SOUTH AFRICA TO SWAZILAND, MOZAMBIQUE AND THE MOZAL ALUMINUM SMELTER IN MAPUTO.

F. Masawi, *Motraco, Maputo, Mozambique*; P. Naidoo and W Majola, *Eskom South Africa*[1]; and T. J. Hammons, *University of Glasgow, UK*

Abstract: The quality of supply delivered to the national utilities in Mozambique and Swaziland and the energy intensive customer, Mozal aluminum smelter, owned by BHP Billiton and others, is defined as world class. Two series compensated 400 kV transmission lines provide the 1,300 MW of electrical energy, on an N-1 reliability design criteria, to the participating customers. The joint venture company, collated the skills and experiences of its three shareholders and directed the focused effort to provide reliable electrical energy to the aluminum smelter which now produces the highest quality aluminum in the world. This excellent service delivery leading to substantial customer satisfaction has contributed to the application for more power and presents an opportunity for growth and long term sustainability of the joint venture, which has become a role model for regional co-operation and integration.

Index Terms: Quality of electricity supply in Southern Africa, bulk power transmission in Southern Africa, reliable electricity supply in Swaziland and Mozambique, Mozal aluminum smelter in Mozambique, energy development and utilization.

I. INTRODUCTION

The signing of the SADC treaty in August 1992 strengthened closer cooperation between member countries of southern Africa. In October of the same year, civil war in Mozambique ended with the signing of a peace treaty between the warring entities. The first democratic elections were held in the same year as well. 1994 heralded the end of apartheid policies in South Africa and the first democratically government took office.

The members of SADC signed, in August 1995, an Inter-Governmental Memorandum of Understanding (IGMOU) that led to the establishment of the Southern African Power Pool (SAPP). The SAPP brought closer cooperation between power utilities in the SADC in power generation, transmission and trade.

In January 1997 governments of Mozambique and of South Africa signed an IGMOU for the development of hydroelectric potential and associated high voltage transmission lines in Mozambique. In March 1997 the government of Mozambique and Alusaf, which became Gencor and now BHP Billiton, signed a Heads of Agreement for the establishment of an aluminum smelter in Mozambique that would be supplied with power from Eskom of South Africa. In June 1997 an electricity tariff for the Mozal aluminum smelter was agreed to between Eskom and Alusaf.

II. ESTABLISHMENT OF MOTRACO

Whilst an agreement was reached for power for Mozal to be supplied from South Africa, Eskom does not have a license to sell electricity in Mozambique. Electricidade de Mozambique (EDM) does not have sufficient transmission capacity to supply the 900MW demand for the smelter. The national power

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[1] Naidoo and Majola served as Technical Directors whilst Masawi has served as General Manager since inception
T. J. Hammons is Chair of International Practices for Energy Development and Power Generation, University of Glasgow, UK

utilities of Mozambique (EDM), South Africa (Eskom) and Swaziland (Swaziland Electricity Board (SEB)) agreed to create a Special Purpose Vehicle registered in Mozambique as Companhia de Transmissão de Moçambique, SARL and also known as Moçambique Transmission Company (Motraco). This is a equally owned joint venture company for the purpose of, among other things, supplying the aluminum smelter, primarily as the transporter of the electrical energy from South Africa to Mozambique via Swaziland. The company working structure is provided in Figure 1.

III. AUTHORIZATIONS AND CONCESSIONS

In March 1998 the government of Mozambique approved the Motraco project with certain fiscal benefits. Concession contracts were entered into between Motraco and each of the governments of Mozambique, South Africa and Swaziland for the:

- Design, financing, construction, ownership and operation and maintenance of transmission lines within their national territories,
- Importation of energy for direct sales to Mozal (currently the energy is imported from Eskom)
- Transportation of energy on behalf of EDM, SEB and ESKOM,
- Establishment of a fiber optic cable network on its transmission lines to ensure the reliability of electrical supplies to the aluminum smelter.

In Mozambique, the Concession Contract between Motraco and the government includes a transmission license. A transmission license was issued to Motraco by SEB in April 1999. In South Africa the National Electricity Regulator (NER) issued a transmission license. Concession fees are payable to the governments of Mozambique and Swaziland. A Joint Commission for Motraco (JCM) comprised of department of energy officials of the three governments exists to attend to political issues that may affect the smooth operations of the joint venture.

Figure 1 summaries Motraco's relationships with its stakeholders i.e. customers, suppliers, shareholders, financiers, board and employees. These relationships are governed by contracts that exist between Motraco and all its stakeholders.

IV. OPERATIONS

Trans Africa Projects (TAP) managed all the Motraco construction projects as a consultant supervising the principal contractors ABB, Alstom and Siemens. The 1,340MW power transmission infrastructure with an N-1 reliability design criteria, comprises of:

- 2 x 400kV transmission lines, one from Arnot Power Station in South Africa to Maputo substation in Mozambique and the other from Camden Power Station in South Africa to Maputo substation via Edwaleni II substation in Swaziland.
- 3 x 132kV transmission lines from Maputo substation to the Mozal smelter near Maputo.
- 2 x 100MVAr shunt reactors at Maputo substation
- 1x 535MVAr & 1 x 344MVAr 400kV fixed series capacitors at Barberton substation in South Africa on the Arnot – Maputo transmission line and at Maputo substation on the Edwaleni II – Maputo transmission line.
- 2x 150MVAr, 400kV and 2 x 72MVAr, 275kV shunt capacitors all at Maputo substation.
- 3 x 500MVA, 400/132kV power transformers at Maputo substation

- a 400MVA, 400/275kV power transformer at Maputo substation and the 275kV Maputo substation to Influene substation via Matola substation was built by Motraco on behalf of EDM in order to interconnect the EDM network to that of Motraco.
- 24 core OPGW fibre optic cables from Maputo to Camden via Edwaleni substations as shown below.

The control, operations and maintenance of the above mentioned infrastructure is outsourced by Motraco to Eskom who has to deliver services equal or better than the targets specified in the various electricity supply agreements and service contracts. To date, the availability and quality of supply targets have been met in all cases and exceeded in some. Capacity shortfalls during the peak periods have resulted in a number of load curtailments to the smelter, but within the provisions of the supply contracts.

The high availability and quality levels of supply have resulted in Mozal producing the highest quality of aluminum, which is branded "Mozal" on the London Metal Exchange. This excellent service delivery by Motraco has contributed to the customer requesting for additional power. This request provides tremendous opportunities for the growth of Motraco as well as the economies of the three countries in which Motraco operates. The world class technical performance is demonstrated by the performance report for the month of December 2006 as shown in tables 1 to 3 and graphs 1 to 3. The monthly report is representative of all other months and the incident or event free performance makes difficult the analysis of the data. This excellent performance can be attributed to the careful selection of the equipment specification for the operating environment. Of particular note, the project employs two 400 kV series capacitor banks, one of the world's largest installations in FACTS technology. Performance to date has been exceptional.

V. FINANCIAL PERFORMANCE

The Motraco income statement and balance sheet as at 31 December 2005, prepared in accordance with International Financial Reporting Standards, are as shown in table 4. A comparison with the 2004 financial results is also given therein. The increases in operating and financial costs as well as taxation in 2005 resulted in a 2MUSD decrease in profits compared to 2004 results. Readers of the statements should note that while current liabilities exceed the current assets, the going concern concept was applicable to the business as the 25MUSD short-term bridging loan, which is part of current liabilities, was converted into a long-term loan in 2006.

For statutory purposes, revenues are reported in accordance with the Mozambican Commercial Code and Tax Legislation and the Generally Accepted Accounting Principles in Mozambique. Under this perspective, revenues and costs from invoiced electricity purchases and sales would also be recognized. At total invoiced revenues (66MUSD for energy and 18MUSD for wheeling charges) of 84MUSD in 2004 Motraco was the ninth biggest company in Mozambique in terms of revenues reported in accordance with Mozambican law.

IV. CONCLUSION

The partnership between the private sector companies BHP Billiton and Motraco and public sector companies EDM, Eskom and Motraco, the governments of Mozambique, South Africa and Swaziland and regional and international financiers has resulted in the production of high quality aluminum in Mozambique. Motraco has become a living example and role model for regional cooperation and integration and its model is and will be emulated in the SADC region and beyond.

The reliability of power supplies in Mozambique and Swaziland as well as the transfer of technical, managerial and financial skills, enabled by the Motraco project, has impacted positively on the economies of these two countries and indirectly of all the SADC countries. Motraco, as part of its corporate social responsibility is making a positive contribution to the communities in which it operates through its participation in sustainable community developmental projects.

Table 1. Incidents for the Month of December 2006

Description	Current Month
A. Camden – Edwaleni 400kV line	0
B: Edwaleni – Maputo 400 kV Line	1 Storm P/E Fault
C: Arnot - Maputo 400 kV line	1 Storm P/E Fault
D: Mozal I 400 / 132 kV transformer	0
E: Mozal I 132 kV line	0
F: Mozal II 400 / 132 kV transformer	0
G: Mozal II 132 kV line	0
H: Mozal load shed	0
I: Maputo – Motola 400 / 275 kV transformer	0
J: Maputo – Motola 275 kV line	0
K: Maputo 400kV Series Capacitor banks	0
L: Barberton 400kV Series Capacitor banks	0

Table 2. Continuity of Supply for December 2006

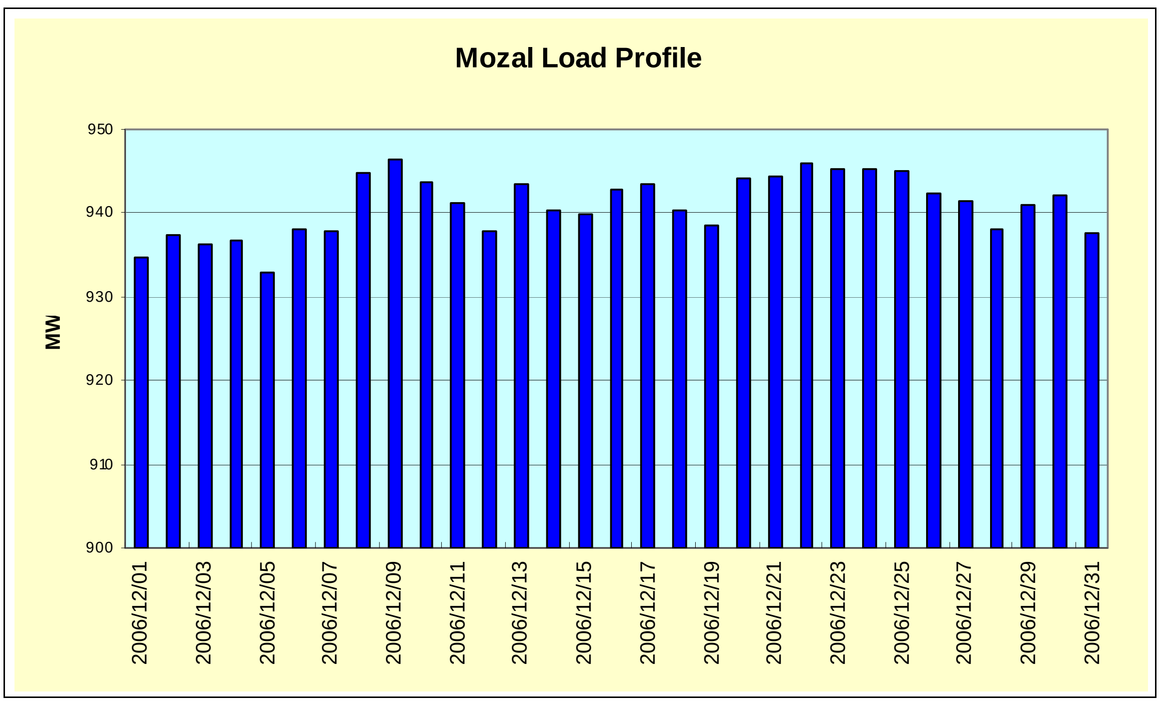
Measure	Current Month
Number of interruptions Mozal EdM SEB **Average duration of interruptions** Mozal EdM SEB **Average load interruptions** Mozal EdM SEB	 0 0 0 0 0 0 0 0 0

Table 3. Equipment Performance for December 2006

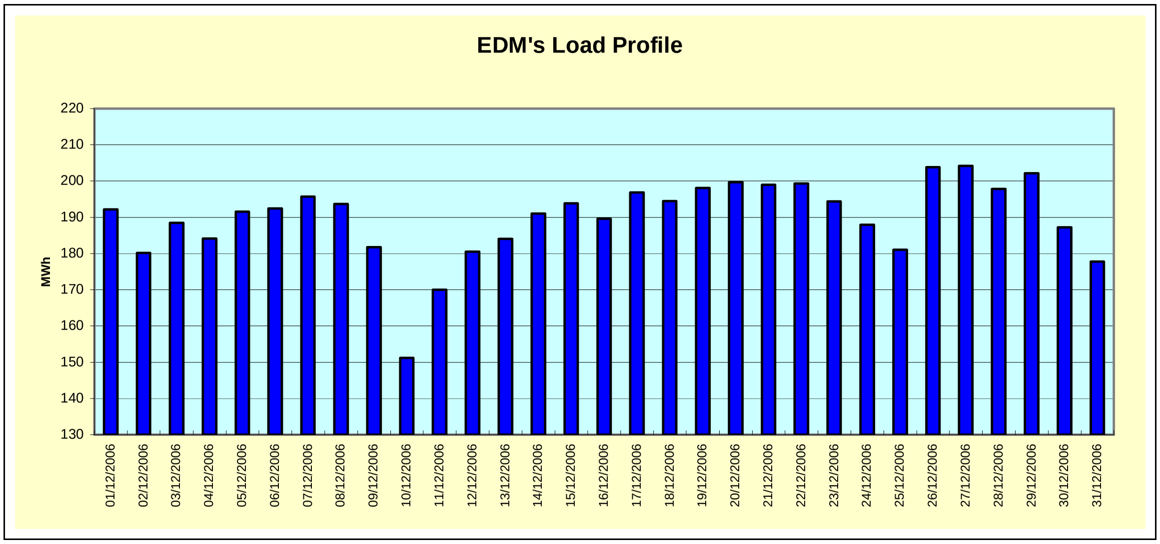
Measure	Current Month
Failures:	
Transformers	
400MVA Infulene	0
Trfr	0
500MVA Mozal	0
Trfr 1	
500MVA Mozal	0
Trfr 2	0
Reactors	
Maputo line	0
Reactor	0
Maputo Bus	
Reactor	0
Capacitor banks	0
Maputo Sub	
Barberton Sub	
CT	0
Maputo Sub	0
Edwaleni II Sub	
VT	0
Maputo Sub	0
Edwaleni II Sub	0
Auxiliary items	0
Maputo Sub	0
Edwaleni II Sub	0
Feeders (Lines)	0
Arnot – Maputo	0
Camden –	
Edwaleni II	
Edwaleni II–	0
Maputo	0
Mozal line bank 1	0
Mozal line bank 2	
Maputo - Infulene	0
Protection operations:	0
Transformers	
400MVA Infulene	0
Trfr	0
500MVA Mozal	
Trfr 1	
500MVA Mozal	0
Trfr 2	0
Reactors	
Maputo line	0
Reactor	0
Maputo Bus	
Reactor	
Capacitor banks	0
Maputo Sub	0
Barberton Sub	
	0
CT	1
Maputo Sub	
Edwaleni II Sub	0
VT	1
Maputo Sub	
Edwaleni II Sub	0
Auxiliary items	0
Maputo Sub	
Edwaleni II Sub	0
Feeders (Lines)	0
Arnot – Maputo	
Successful	0
ARC	0
Unsuccessful	
ARC	0
Camden –	0
Edwaleni II	
Successful	0
ARC	0
Unsuccessful	
ARC	0
Edwaleni II–	0
Maputo	

Successful ARC	
Unsuccessful ARC	
Mozal line bank 1	
Successful ARC	
Unsuccessful ARC	
Mozal line bank 2	
Successful ARC	
Unsuccessful ARC	
Maputo - Motola	
Successful ARC	
Unsuccessful ARC	
Bus Isolations:	
Bus zone	
Maputo Sub	
Edwaleni II Sub	
Bus strip	
Maputo Sub	
Edwaleni II Sub	

Graph 1: Mozal Aluminum Smelter Load



Graph 2: Mozambique National Utility EDM Load Profile



Graph 3 : Swaziland SEB Load Profile

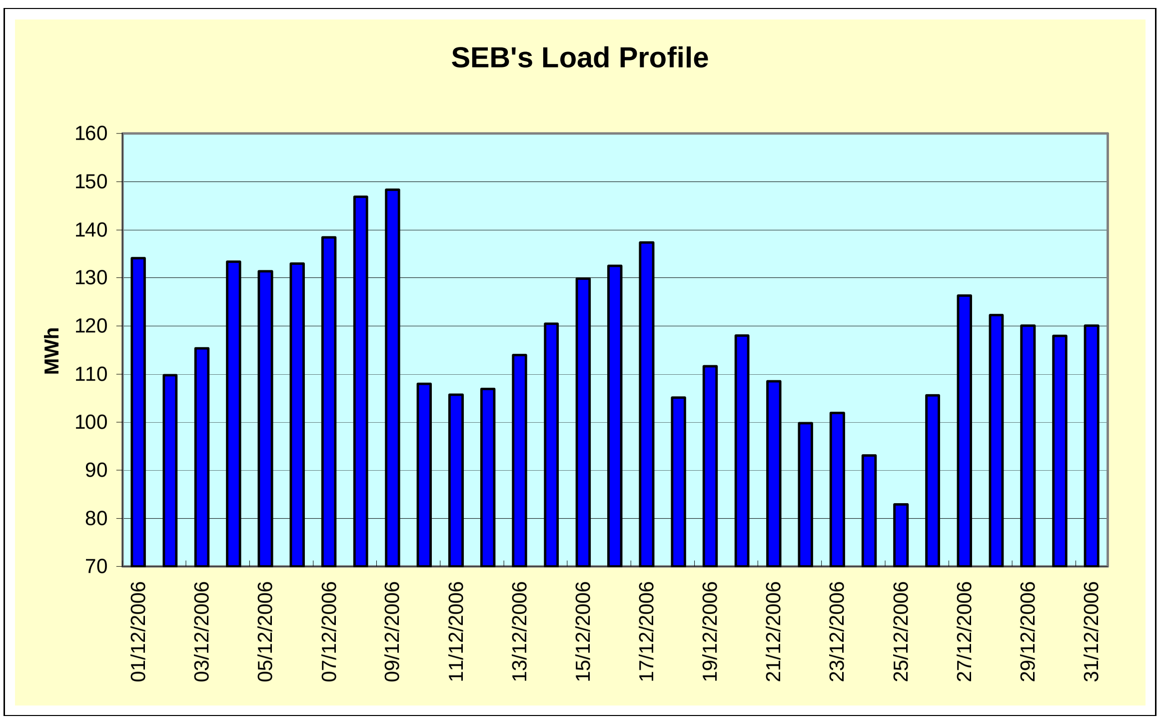


Table 4. Financial Performance

Income statement as at 31 December 2005.

	2005 USD	2004 USD
Revenue	**18 341 779**	18 058 252
Operating expenditure	**(9 581 583)**	(8 936 292)
Operating profit before financing costs	**8 760 196**	9 121 960
Financial income	**398 237**	563 715
Financial expenses	**(5 785 223)**	(4 266 313)
Net financing costs	**(5 386 986)**	(3 702 598)
Profit before tax	**3 373 210**	5 419 362
1.1.1.1.1 Income tax expense	**(379 317)**	-
1.1.1.1.2 Profit for the period	**2 993 893**	5 419 362
Basic earnings per share	**7.58**	13.72

Balance sheet as at 31 December 2005.

	2005 USD	2004 USD
Assets		
Property, plant and equipment	**116 659 678**	122 152 922
1.1.1.1.3 Total non-current assets	**116 659 678**	122 152 922
Trade and other receivables	**4 873 345**	3 662 993
Cash and cash equivalents	**6 296 712**	4 409 830
Total current assets	**11 170 057**	8 072 823
Total assets	**127 829 735**	130 225 745
Equity		
1.1.1.1.4 Capital and reserves		

Issued capital		**37 737 531**	37 737 531
Reserves		**6 825 289**	6 608 473
Retained earnings		**3 952 710**	1 182 938
1.1.1.1.5	***Total equity***	**48 515 530**	45 528 942
Liabilities			
Interest-bearing borrowings		**44 527 423**	52 504 429
Total non current liabilities		**44 527 423**	52 504 429
Interest-bearing borrowings		**31 213 658**	29 383 189
Trade and other payables		**3 193 807**	2 809 185
Income tax payable		**379 317**	-
Total current liabilities		**34 786 782**	32 192 374
Total liabilities		**79 314 205**	84 696 803
Total equity and liabilities		**127 829 735**	130 225 745

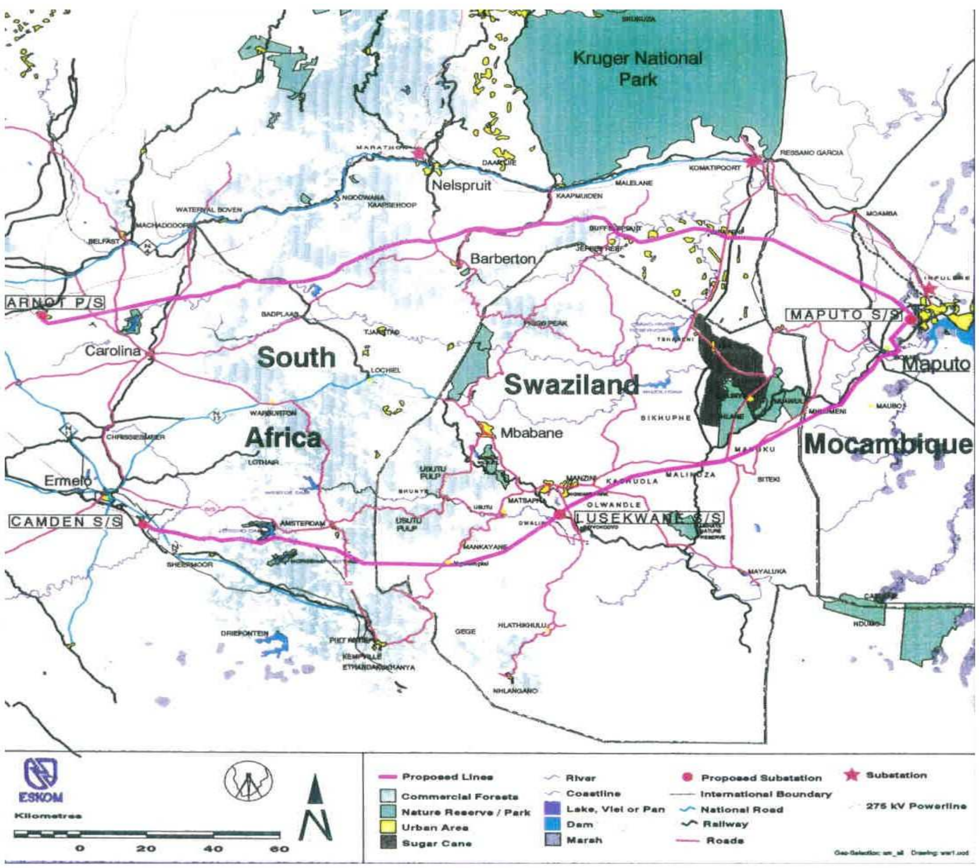


Figure 2. Power Transmission Layout Across 3 Countries

VII BIOGRAPHIES

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Thomas James Hammons (IEEE Fellow '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. His contact E-mail is T.Hammons@ieee.org

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7. HYDROPOWER PLANNING IN EGYPT, SUDAN AND ETHIOPIA. (INVITED DISCUSSION).

Tom Sparrow and Brian Bowen, Purdue University, USA. Hydropower Planning in Egypt, Sudan and Ethiopia. (Invited Discussion).

Over the past few years the East Africa region has been promoting the creation of an East African Power Pool (EAPP). East Africa has several major initiatives that combine new capacity expansions with utility restructuring and the creation of appropriate utility regulatory frameworks. The Ethiopian Electric Power Corporation (EEPCO), plans to construct several new generating facilities. Kenya's over-reliance on hydroelectricity and the effects of prolonged droughts provide the background for the construction of the Olkaria II geothermal station. Uganda is an electricity exporter to Kenya and plans to significantly raise it's level of exports into Tanzania and Rwanda. Sudan's additional generating capacity at the Nile's fourth cataract, with the Merowe facility of 1,000MW, and improvements to the nation's grid in the Blue Nile Grid and the Western grid sections are strategic initiatives for the East African electricity industry. Uganda's Bujagali dam project will be the largest foreign direct investment project within the region. Consortia are being formed to build facilities in this region with various international companies and investors.

The Purdue energy modeling team has been invited by Electricite De France (EDF), the successful bidder for the USAID funded regional electricity infrastructures project, to be a part of their proposal. A project commencement date is not yet settled."

Received February 2 2007

8. A SYSTEM DYNAMICS APPROACH TO UNDERSTANDING THE DEVELOPMENT OF THE KENYAN ELECTRIC POWER SECTOR (Paper 07GM0967).

Katherine Steel, Massachusetts Institute of Technology (MIT), Program on Emerging Technologies (PoET), Laboratory for Energy and the Environment (LFEE), Bldg. E40, 77 Massachusetts Avenue, Cambridge, MA 02139, USA. E-mail: ksteel@mit.edu

***Abstract*:** In many African countries there is a tension between grid and off-grid electric service provision and it is unclear whether a centralized or decentralized power system architecture will emerge. This paper explores some of the dynamics of system development in Kenya, where poor grid infrastructure has resulted in a thriving private market for photovoltaic panels and a growing number of industries are investigating shifting to on-site generation. The research is based on ethnographic interviews and observations in Kenya and uses System Dynamics modeling tools to analyze qualitative and quantitative feedback in the system.

Keywords: Electricity, Africa, System dynamics

I. INTRODUCTION

In the developing world more than 1.6 billion people are without access to electricity[1]. Sub-Saharan Africa (SSA) and India are the least electrified regions of the world and they continue to fall further and further behind (See Figure 1). Although the lack of modern energy services in these regions is well documented, the underling reasons are not well understood. This research focuses on the growth of the electric power system in the SSA country of Kenya, and explores both the dynamics which have led to the low availability of power, as well as the drivers which could enable greater access in the future.

Seventy percent of people in SSA live in rural areas and rural electrification rates are extremely low. This presents a challenge for electrification because it is expensive to connect a diffuse population. Both the line losses and cabling costs due to long transmission distances make installing the infrastructure very costly. This technical limitation, added to the fact that the majority of the rural population has little ability to pay for electric service, makes it economically impossible to extend the grid to all areas. The only justification for rural electrification has been the social necessity.

Lack of electricity and modern fuels can be linked to an increase in disease and environmental degradation, and economic stagnation. Homes without electricity continue to use biomass and kerosene for cooking and lighting, which leads to respiratory and eye infections. These households also deplete biomass resources, which can increase desertification and cause land erosion. Lack of modern energy sources can inhibit education due to poor lighting conditions and inhibit economic growth due to the time used gathering traditional fuels and the inability to expand businesses using more efficient energy sources.

K. Steel is with the Laboratory for Energy and the Environment (LFEE) at the Massachusetts Institute of Technology (MIT). She is funded through the Program on Emerging Technologies (PoET). Email: ksteel@mit.edu

Even in urban and industrial areas electricity access is low. While most industries are located near the central grid, many must invest in back-up power supplies and power smoothing equipment to manage the frequent outages and inconsistent voltage supply in the network.

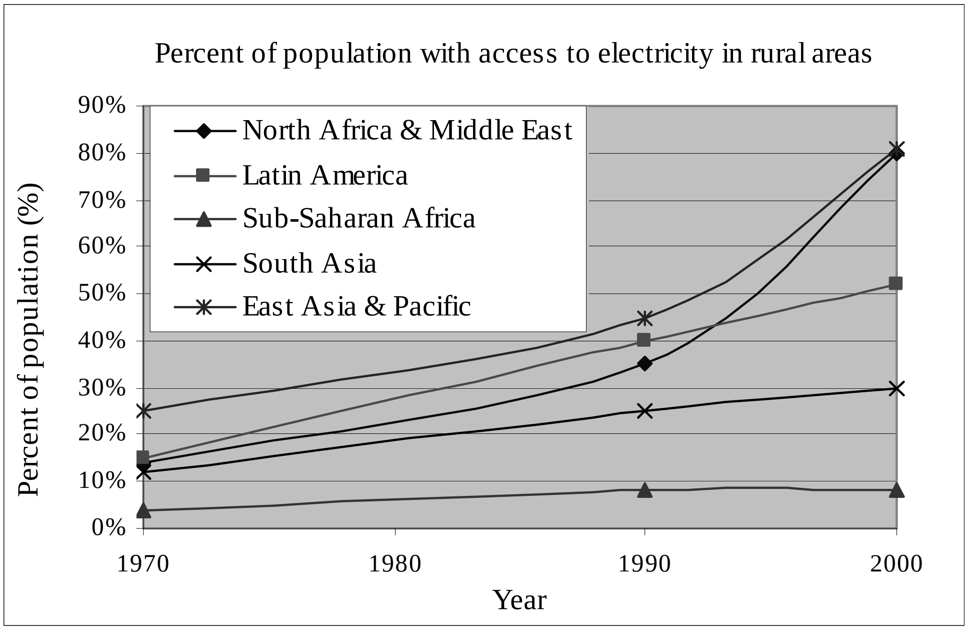

Figure 1. Percent of rural population with access to electricity by regions [1], [2]

This paper describes a system dynamics approach to analyzing electric power system development. The systems approach uses both quantitative and qualitative data to understand the dynamics which drive growth in the system. This qualitative data collection uses ethnographic methods to understand the stakeholders' decision-making processes and their interactions. System dynamics modeling is used to map the interactions and to understand the feedback in the system. This model is not intended to be predictive. The goal of the research is to show intervention points where policy choices could have an impact on the future development of the system.

II. ELECTRICITY IN AFRICA AS A COMPLEX SYSTEM

Discussions of complex systems usually focus on computer networks, transportation systems, or manufacturing logistics. However, African electric power systems are complex infrastructure where the architecture is not already determined. While most complex systems research focuses on existing complexity, in Africa there is an opportunity to study the system as it develops. So far there has been little research to understanding system development in this area. Karekezi and Kimani [3] and Pandey [4] have noted the lack of research in African power systems and the insufficient use of modeling in developing countries, respectively. Hammons et al. [5] also cite this need with reference to the World Bank, saying that, "[it] has not yet found a reliable model for dealing with the special needs of sub-Saharan Africa electricity infrastructure."

One source of complexity that is not well understood is the choice between a centralized grid system and a decentralized system. The centralized grid architecture was developed initially for urban populations where there are densely packed clusters of people. Even in rural areas of most industrialized countries there may be great distances between the nodes of the network, but each node represents a large demand for electricity. African population patterns are more scattered and the nodes have far less demand. Africa faces a choice between following the traditional model of centralized generation, or developing a decentralized model. There are benefits and detriments associated with both options. While a decentralized model may make it easier to provide service to remote populations, it may limit system growth in the future. Were an inexpensive bulk power supplier to come online, such as the Grand Inga hydropower station in the Democratic Republic of Congo, a country with a decentralized system might have difficulty benefiting from this source.

If the choice were simply a technical one, the system could be analyzed and optimized according to the least cost or most technically efficient model. However, there are several non-technical issues which add complexity. As mentioned previously, most governments now see electricity as a social right. If an optimization model were to show it is uneconomical to provide any access to certain areas, this would not meet the desired goal of the system. There is also an issue of complexity due to corruption. Any planning which ignores the presence of corruption does not reflect the true cost of implementation. This problem of non-technical complexity highlights the need for new approaches to system analysis in Africa.

III. SELECTION OF CASE STUDY

This research focuses primarily on East Africa, and specifically Kenya. Kenya typifies the difficulties of energy development in eastern Africa, with its low population density and an installed capacity of only 1147 MW. Kenya is also a regional economic and political anchor and ideally development in Kenya will positively impact Uganda and Tanzania[3], as well as other countries in the region.

The scope of this research covers the range of electric power consumers and generators in Kenya, as well as the organizations that sell and regulate power. Kenya has privatized power generation with roughly 70% of generation by the Kenya Generating Company (KenGen). The remainder is provided by independent power producers (IPPs). Electricity is sold to Kenya Power and Lighting Company (KPLC), who sells to consumers, and the sale on both sides is regulated by the Electricity Regulatory Board (ERB). Consumers who are not connected to the national power grid have the option to buy off-grid generating equipment from dealers. Figure 2 shows the scope of the case.

[3] Kenya, Uganda, and Tanzania have existing cooperation agreements under the East African Community alliance. Kenya and Zambia are also working together to create a link that will bring power from the Southern African Power Pool into East Africa.

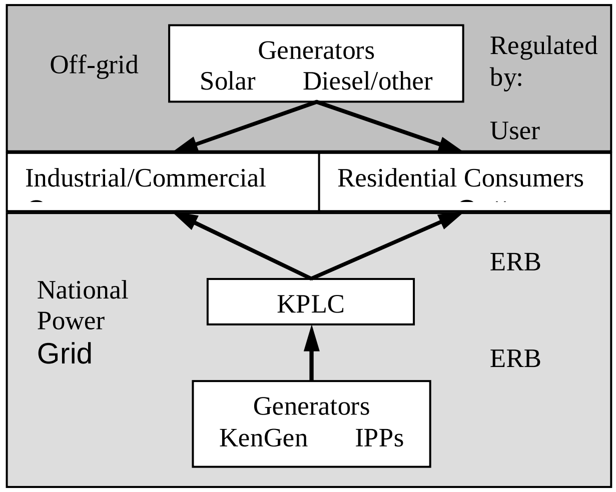

Figure 2. Scope of analysis of Kenyan electric power system

The case study concentrates on the interaction of the actors in the system and how their decisions feed back into the system and affect its development. The method used in this research was selected because it seeks to understand qualitative, as well as quantitative, aspects of the system.

IV. METHOD

The goal of the method is to understand why electricity access is stalled in SSA, and what can be done to enable growth. System dynamics modeling is appropriate method in this case because it can represent the range of technical and non-technical feedback in the system. For the model to be useful, however, it must be grounded in reality. Sterman [10] found participant interaction and interaction with clients essential to formulating the non-linear functions of a model, which points to the use of interviewing and observation as methods. The fieldwork for this study followed the standard method for system dynamics modeling [10]. This includes attention to stakeholder interaction, causal loop diagramming, calibration, and sensitivity analysis.

The interviews conducted in Kenya included residential and industrial consumers, representatives from KPLC, KenGen, and the ERB, and off-grid service providers. A final source of information was quantitative data collected in Kenya, both concerning the operation of the power system and the socio-economic status of the population. The data gathered from these sources are being used in the creation of the system dynamics model.

There are many existing models of the electricity sector and technological growth which are being used for guidance. Potential structures include: Diffusion of technology (Bass model), Decision-making, Pricing strategy, and Boom and bust. For example, the Bass diffusion model could be used to explain the spread of PV home systems in Kenya. Van der Plas and Hankins [11] found that 94% of solar home system users they surveyed would recommend the system to a friend, which mimics the "word of mouth" function in the Bass model. Another example is Andrew Ford's use of the boom and bust model to study the electricity sector in California [12]. A similar model could be used to show the pattern of under-investment in Kenyan power generation.

As stated earlier, this model is not intended to be predicted. Rather it could be used to identify points were policy could have an impact. Saeed and Prankprakma used system dynamics to study the link between technological development and economic growth. They found that technological development has the potential to be a policy lever for economic growth in developing economies but only if a feasible path can be determined [13]. Similarly, this research is attempting to find policies for inducing development in the energy system.

V. PRELIMINARY FINDINGS

Although data is still being compiled, the interviews have given some preliminary insight into the dynamics of the electric power system growth in Kenya. One of the key findings may be that Kenya, and Africa in general, is not so different from the rest of the world in terms of electrification. Instead of focusing on what makes Africa different, perhaps policy-makers should be focusing on how it is the same.

Grid infrastructure in Kenya is characterized by high fees and long waits for connections, large voltage fluctuations, and relatively common outages. Standby power supply in Kenya has become so common that commercial and residential customers accept frequent interruptions in the power supply. Even in very modern commercial centers or tourist hotels, power interruptions are not met with surprise, rather the customers simply pause while the generators automatically come online and then go about their regular activities. This is not the case with industrial consumers. Manufacturing and production processes frequently cannot simply restart if there is a power interruption. A food processing plant outside of Nairobi estimated that for every power interruption they lost four hours of productivity due to spoilage of the product and the need to reset and clean all processing equipment. In this case the feedback is that as power interruptions become more of a burden to the customer, the more likely they are to seek other sources of electricity.

Most commercial and industrial consumers that have been interviewed have said that if there were a standby power supply that could compete on cost with the grid, they would consider producing their own power. Already several large consumers, such as sugar, tea, and paper manufacturing companies, generate a portion of their own power. The Kenya Tea Development Authority (KTDA) has assessed the feasibility of on-site generation at 20 more of its tea factories and Mumias Sugar recently signed an agreement to expand its boiler capacity to generate 35 MW on site.

If a significant portion of industry disconnects from the grid, or generates the majority of their own power, it will reduce the revenue to the Kenya Power and Lighting Company (KPLC). If this happens, it could hinder KPLC's ability to invest in infrastructure, which would in turn encourage more consumers to move off-grid. This dynamic has already been seen in the telecom sector in Kenya. The national provider, Telkom, was ill-equipped to manage the introduction of competition from mobile phones. As their customer base shifted to solely using mobile phones, they no longer had funds to meet the cost of maintaining even the existing system.

Residential consumers are similarly choosing to go off-grid. Estimates vary as to the total number of PV panels sold, but consensus says it is well over 100,000 units. In most rural cities the electrical appliance shops sell PV panels and systems and several large retailers and wholesalers, such as Davis and Shirtliff and Chloride Exide, operate across the country. According to interviews with dealers, customers choose PV in most cases because they are not close enough to the grid to be connected. However, some are buying PV even after having paid for a connection to KPLC, because after waiting several years they have still not been connected. Others decide to keep using PV even when the grid comes to their village since they have already made the investment.

Although the feedback to KPLC is the same for residential consumers, that every person who chooses to generate on-site is lost revenue, the impact is not as significant. Especially for rural users, the per person consumption levels are so low that the loss in revenue is unlikely to be as significant for KPLC.

Kenya, like many African countries, is at a critical point in its electric power infrastructure development. Depending on where investment is focused, the system could grow as an interconnected grid with generation flowing out of power stations, or it could become a decentralized system where industrial and residential power consumers generate power on-site. Even if the on-site generators remain connected to the grid, the technical and financial structure of the system will shift. In the US city of Chicago in the late 1800s, there was a surprisingly similar tension between dedicated power suppliers and industry and businesses generating their own power on site. In that case, the system shifted to a centralized utility when Samuel Insull was able to cut costs for power producers through increasing load factor and diversifying customer demand [19]. In Kenya, it is important to understand how these type of policies and investments could impact the system development.

VI. CONCLUSIONS

At this stage it is still too early in the research to know the conclusions. However, several key ideas have emerged. The guiding question is whether Kenya, and other African countries, will develop a decentralized or centralized grid, and what will be the implications of either development. Included in this problem are the questions of what will drive development of the system, whether it will be industry or government. There is also a question of the role of corruption and whether its presence is the limiting factor in system growth, Finally, this research will also question whether Africa is really all that different from other regions in its power system development. If the dynamics are similar to other regions which have already gone through this process, then that may lend insight into how to spur development.

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9. PROVIDING ELECTRICITY SERVICES TO RURAL AFRICA (PAPER 07GM1035).

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***Abstract*—**The international community has set ambitious goals aimed at improving the quality of life in Africa. Initial delivery of electric service to rural Africa is far from a "one size fits all" technical solution, especially given the seasonal diversity of energy needs, as well as the availability and quality of candidate renewable energy resources. Nor will be the expansion, and potential integration, of those systems over time be a simple task.

To design, implement and operate cost-effective and reliable rural electricity systems many factors must be taken into account. The technical and economic feasibility of different systems is highly dependent on a diverse set of design criteria: local energy demands (daily, seasonal); available renewable resources (quantity and quality); location relative to conventional fuel supplies and/or grid power; plus how these factors may vary over time. Dynamics among technical and institutional aspects are key, as are understanding the relative economic value of staged electric service introductions. Key design factors towards the deployment of electricity services will be identified and assessed.

Index Terms—Energy Demand, Renewable Resources, Rural Electrification, Strategic Planning

I. INTRODUCTION

It is estimated that roughly 1.6 billion people do not have access to electricity, with most of them being in Africa and South Asia [1], and that without extensive investments in electricity power, this number may still be 1.4 billion by 2030 [2]. With these challenges in mind, the communiqué from G8 meeting in Gleneagles, Scotland in the summer of 2005 called for major action to support economic development in Africa. Even with the World Bank instituting a Clean Energy Investment Framework, the task is still daunting. The Action Plan for meeting Africa's energy service needs include:

(a) Access to clean cooking, heating and lighting fuels, coupled with sustainable forest management;
(b) Scaled up programs of electrification;
(c) Additional generation capacity to serve newly connected households and enterprises, including through regional projects;
(d) Provision of energy services for key public facilities such as schools and clinics; and
(e) Provision of stand-alone lighting packages for households without access to the electricity grid [3].

Why ambitions to meet the Millennium Development Goals by 2015 are laudable, in terms of energy infrastructure design, finance and implementation, and developing the local capacity to operate and maintain those systems, 2015 is very close.

II. UNDERSTANDING THE CHALLENGE

Several understated challenges that technology and finance companies, government agencies, and local communities face is how to design and implement new electricity services in time and space. For example, not all businesses and households in a village or town will receive electricity at the same time. Initially small village scale systems may only electrify community buildings, and then for only several hours per day from a diesel or biogas genset, or micro-hydropower system. However, we know that as communities develop, demand for modern energy services may begin to grow rapidly [4].

Several other daunting challenges to supplying over a billion people with electricity have to do with a) how quickly can electric service be provided – at any level, b) what requirements are there from the viewpoint of grid extension, or the development of parallel fuel supply infrastructures to support generators, and how to maximize economic benefits/ and reduce cost and availability risks as local economies become more dependent on electric service. New tools for optimizing the configuration of village scale power systems, especially those that incorporate renewables are now readily available [5]. However, energy demand is far from static and may vary significantly by time of year (climate, agricultural energy demand), as well as time of day. [6] showed how alternative configurations of wind-diesel systems could meet different levels of village electricity demand (with different economic values).

If local communities wish to tap multiple local energy resources, then their dynamics must also be taken into account. In the case of sun and wind, these may be more predicable than other resources, such as hydropower and biomass, especially if areas are drought prone–or worse–if vegetation is poorly managed.

So, if electricity is to be delivered to rural areas in the near-term, with factors of demand growth, resource dynamics, and system expansion taken into account, a new design approach is needed.

III. DESIGNING ROBUST SOLUTIONS

The history of development aid is littered with no-longer functioning demonstration projects. However, many of these were technological feasibility studies, and for most cases the technology worked–after some tinkering. In the 21st Century, this is insufficient. Integrated energy technology demon-stration projects must become models both for dissemination and training, recognizing full well that local communities must adapt these technologies and systems to suit their own needs and resources, including the ability to keep them running, and pay for operating costs. There are now good templates from small villages in India and elsewhere on how to collect costs from users, and task residents for routine maintenance tasks.

One challenge is to identify a range of “basic systems,” based upon demand levels and pattern, and renewable resource dynamics, that can then be adapted to actual village conditions.

IV. GROWING WITH TIME

As hinted above. Once electric service becomes available, demand for electric service is likely to grow rapidly. As illustrated in Figure 1, over time neighboring villages will install their systems, grow from intermittent to 24 hour service, and with enough planning and coordination, link up their villages to one another and the ever closer centralized grid.

This poses a challenge to standards makers, so that “plug and play” village systems can easily be linked together and operated in a coordinated fashion without facing service quality impacts. The day of resistive loads has passed, and the power quality requirements of “electronified” villages must be respected, and planned for.

C. DESIGNING ROBUST SOLUTIONS

Concurrent with the development of design tools, on illustrative demonstration projects, is the need to collect quality information on changes in and drivers of electricity demand, as well as the patterns and variability in numerous renewable resources (wind, solar, hydro/precipitation, crop yields and forest productivity).

V. CONCLUSIONS – BUILDING THE CONTEXT AND THE CAPACITY

Taking the into consideration the various aspects of the challenge outlined above, it is clear that goals put forth by the UN and OECD can only be pursued by developing numerous “capacities” ranging from international finance and access to “best practice” technologies, to the development of operation, maintenance and small business skills down at the local level.

From a strategic planning viewpoint, “context building” is needed such that the initial provision of electric service cannot only be maintained, but expanded through time in a manner that maximizes both the use of local resources, and puts these new energy services to best economic use.

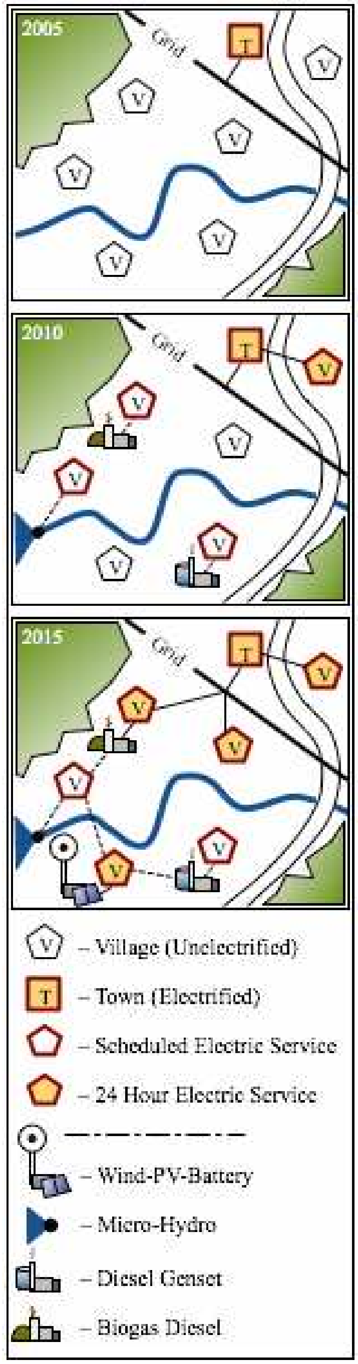

Fig. 1. Diversity and growth of village scale power networks over time.

Building this integrated capacity to electrify 1.6 billion people, whether through grid extension to growing urban areas, to far from grid small population centers, is a very large task. It will take a huge commitment in time, people and money. However, with modern communications and information tools, "best practices" from design to operations should rapidly penetrate the industry and propagate from one local to another.

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Stephen R. Connors is director of the Analysis Group for Regional Energy Alternatives (AGREA) at the Massachusetts Institute of Technology's Laboratory for Energy and the Environment (LFEE). Mr. Connors holds two bachelors degrees from the University of Massachusetts in Amherst. Between the degrees in Applied Anthropology (1980) and Mechanical Engineering (1986), he was a Peace Corps volunteer in Benin, West Africa where he designed wood conserving cookstoves. Following his mechanical engineering degree from the UMass Renewable Energy Research Laboratory, Mr. Connors received his masters in Technology and Policy from MIT (1989) where he was a founding member of AGREA, which employs a multi-attribute tradeoff analysis approach to identify robust, long-term energy systems pathways which meet combined economic, environmental, reliability and other objectives. Mr. Connors has led numerous research projects in the USA, Europe, Latin America and China, and now leads the "Near-term pathways to a sustainable energy future" coordinated research education and outreach program of the Alliance for Global Sustainability, a partnership among MIT, the University of Tokyo, the Swiss Federal Institute of Technology, and Chalmers University of Technology.

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10. EXPLORING A SYSTEMS DYNAMICS APPROACH TO INSTITUTIONAL DEVELOPMENT AND INTEGRATION IN THE AFRICAN POWER DEVELOPMENT SECTOR (PAPER 07GM0915)

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Abstract--This paper attempts to further the development of previous recommendations made for institutional and manpower development efficiency to support the growing African Energy Sector. Developing and standardizing a curriculum at strategically selected technical centers and universities throughout the countries of the various regional power pools are the compelling strategic recommendation of this study. Towards this end, this paper introduces an exploratory Systems Dynamics approach to further develop a previously proposed All Africa integration model (2004, 2005). Concepts from Systems Engineering are also used to strengthen the thesis that African Policy makers can effectively capture and leverage the information mass created by the planning and development of some of these Power Generation and Transmission initiatives to develop policies and standards across a spectrum of associated disciplines. Data from ongoing projects across a wide generation profile and fuel mix in the South African power pool (SAPP) and West African Power Pool (WAPP) are good primary candidates for modeling. Their evaluation includes manpower deficiencies; environmental issues, Grid fortification and regional integration and domestic challenges brought on by increasing Load Demand outpacing Generation. Future integration with Central African Power Pool (CAPP), East African Power Pool (EAPP) and interconnection initiatives in North Africa with ties to the Middle East are also discussed.

Keywords-- Systems Dynamics, Feedback, Knowledge Management, Ba

DEFINITION:

AAU - The Association of African Universities
ICT - Information, Communications, Technology
AVU - African Virtual University
EPRI - Electric Power Research Institute
SST - Strategic Science & Technology

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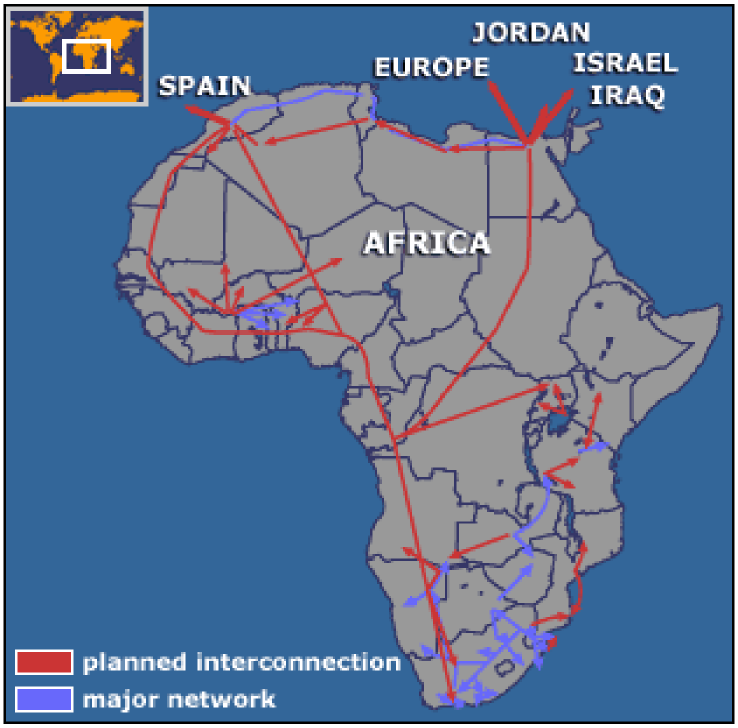

Fig. 1

I. INTRODUCTION

This study seeks to further examine an institutional framework suggested by the 'knowledge engine' model of Fig.2 previously presented (2004, 2005) ref.10, 12. This paper's focus is to explore the question a) *how is the knowledge captured from the engine?* b) *how is it distributed and applied in the various synthesized forms of the output generated?* The multidisciplinary nature of Power Generation and Transmission projects provide an interesting synthesis of knowledge, added to that the dynamic converging and diverging nature of global issues, humanitarian crises, weak infrastructure and manpower deficiencies in the case of Africa speak to the need for magical 'Think-outside-the-box-solutions' (TOTB) to effectively capture and apply this knowledge. While a magical solution would be most certainly welcome to address the most dire of situations one is left with the TOTB solution as a paradigm to uphold much needed optimism to achieve success. As illustrated the previously proposed model is created in broad terms from an examination of various programs and studies from around the world and is then configured to synthesize elements from the various INPUTS to address an African context. The sheer ambition of attempting to configure such divergent disciplines into something practical leaves one open to skeptics were it not for the exigencies of System Dynamics. To quote J.W. Forrester, the founder of system dynamics; "Interest in System Dynamics is spreading as people appreciate its unique ability to represent the real world. It can accept the complexity, no linearity, and feed back loop structures that are inherent in social and physical systems". In educating the individual, the objectives of a systems dynamics education might be grouped under three headings: 1) developing personal skills, 2) shaping an outlook and personality to fit the 21st century, and 3) understanding the nature of systems in which we work and live. The subsequent paragraphs will attempt to borrow concepts from system dynamics to indicate the possibilities even though concrete models (simulation) which are at the core of the studies have not yet been tested specifically for this model.

II. MODEL OVERVIEW

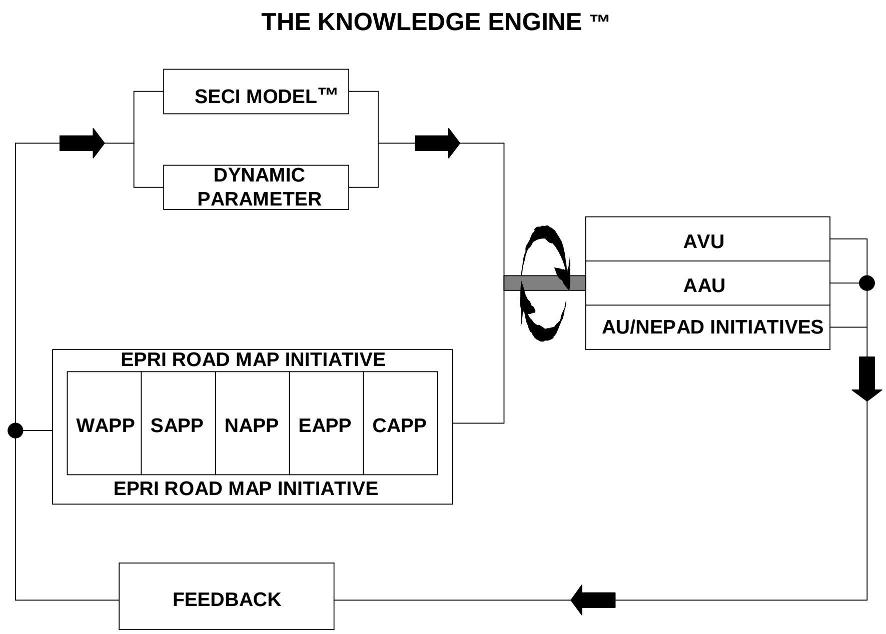

Fig. 2. Model Overview

The African Sectors of focus are the South African Power Pool (SAPP), West African Power Pool (WAPP) and the initiatives in North Africa with interconnections to the Middle East and Europe (NAPP). Studies such as the Purdue long-term economic model and R&D programs from EPRI'S Road Map Initiative & SST 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.Ref.8. 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*

EPRI has adopted a strategy whereby SS&T provides the strategic resources for EPRI's integrated R&D planning process, helping connect the specific technical objectives of EPRI's sector programs with the broad societal goals defined by the Road Map. SS&T concentrates on a set of 15 *limiting challenges* representing critical issues and opportunities facing the electricity enterprise and society along with the associated gaps in knowledge and technological capability. The limiting challenges link the destinations identified by the Road Map with the objectives of EPRI's sector programs. The *15 limiting challenges* listed

- Improved Transmission Capacity, Grid Control, and Stability
- Maintain and Strengthen Portfolio of Generation Options
- Accelerated Development of Carbon Capture an storage Technologies
- Creation of the Infrastructure for a Digital Society
- Improved Methods for Communicating and Applying Scientific Knowledge
- Improved Power Quality and Reliability for Precision Electricity Users
- Increasing Robustness, Resilience, and Security of Energy Infrastructure
- Advances in Enabling Technology Platforms
- Exploiting the Strategic Value of Storage Technologies
- Transformation of Electricity Markets
- Ecological Assessment Management
- High Efficiency End Uses of Energy
- Maintaining and Improving Water Availability and Quality
- Global Electrification
- Development of Electricity-Based Transportation Systems

III. STANDARDIZING CURRICULA

Manpower development remains core to any kind of institutional integration. Our previous study had made the recommendation of creating Community of Practices (COP) utilizing knowledge creation recommendations of the SECI™ Model, which states that in order to make these things happen, there must be "**Ba**" for knowledge creation. **Ba** means internal communities of groups of technologists or knowledge workers who share the same interest or purpose. More specifically, they are cross-functional human networks or groups including virtual relationships on intranets, extranets or the Internet. These communities are called COP (communities of practice). Participants understand the contexts of others and oneself, and through interaction, change/create the contexts. Hence, it is constantly moving.

The key to understand context is interaction. Knowledge does not just reside in one's mind. Knowledge emerges through shared contexts that are created through interaction. (Ref.1a). This author feels that further efficiency can be achieved from the Knowledge Engine by incorporating systems dynamics to mine it's inherent complexity. In so doing a key objective would be the formulation of a "Renaissance Man" or woman as defined by Forrester ref.2.

We have previously stated our proposed knowledge engine is introduced to create knowledge from local and continental conditions as a paradigm to improve efficiency by strengthening institutional integration around specific curricula the challenge then becomes creating curricula that create Virtual Worlds used for improving the learning process ref. 4 J. Sterman. Fig 3 is a basic representation of how a Systems Dynamics approach would initiate a basic level of evaluation of a system.

"System dynamics trains an individual to see the interrelationships in systems as being far more interesting and important than separate details. The interrelationships reveal how the feed back loops are organized that produce behavior. Students with a background in systems modeling should be sensitized to the importance of how the world is organized. They should want to search for

interconnecting structure that gives meaning to the parts. System Dynamics provides a foundation underlying all subjects"ref.2.

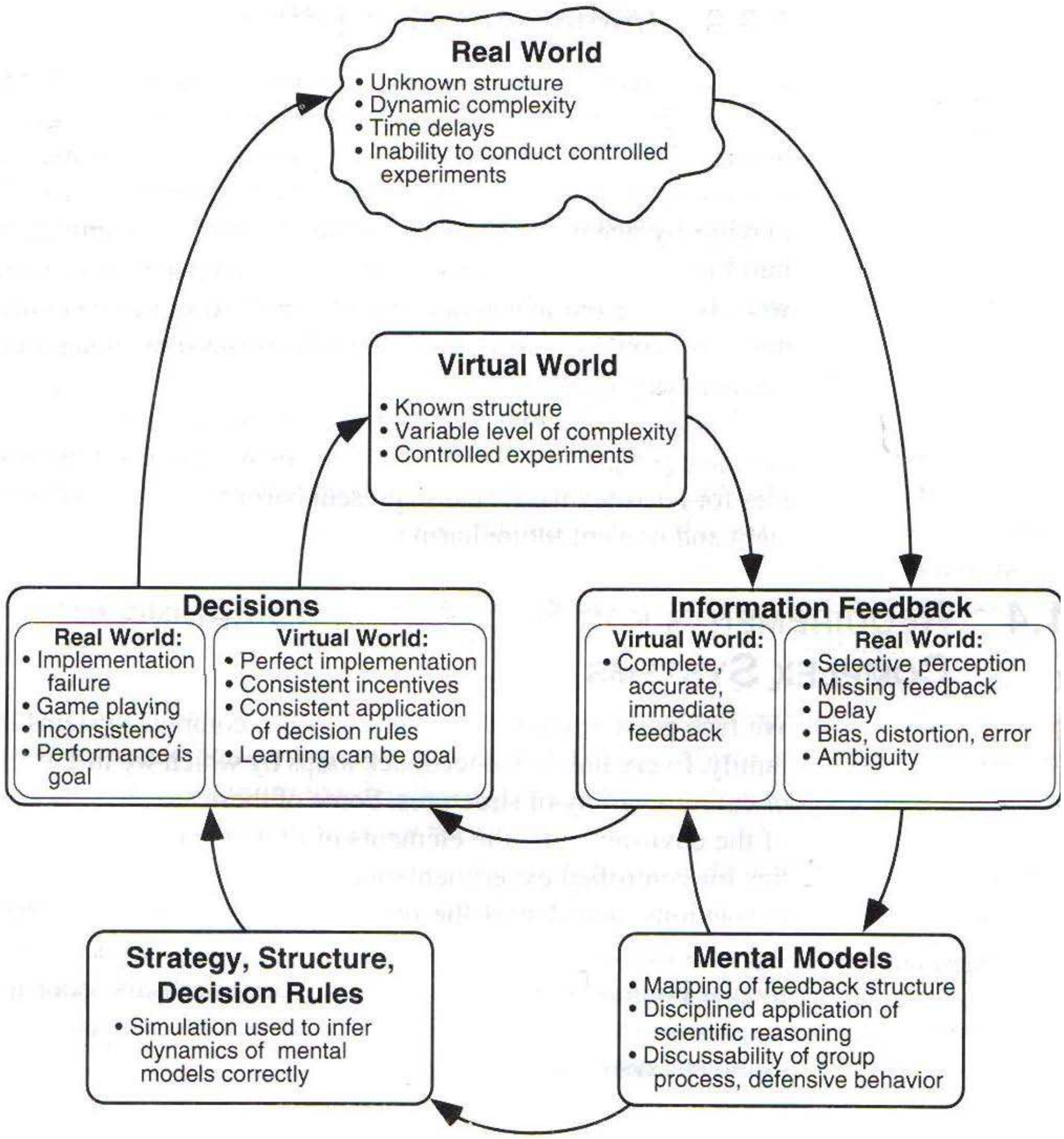

Fig. 3 Systems Dynamics Representation

Fig.3 represents an idealized learning process whereas effective learning involves continuous experimentation in both the virtual world and real world. Feedback from both informs the development of mental models, formal models and the design of experiments for the next iteration. Ref. 4

IV. THE POWER DEVELOPMENT FOOTPRINT

The focus on Generation as a knowledge base is because of the societal impact information before during and after its development. Simulation of societal impact to address a societal problem is it's itself a contribution to the student body's social consciousness. Sharing that consciousness/knowledge among the body of coordinated participants in a local regional or international context creates a dynamic of new ideas and the potential for multiple solutions from a variety of sources and disciplines. The WESTCOR project in South West Africa is one such 'opportunity project' whose large footprint covering a large resource laden geographical area can influence the training of a large student body in Systems Thinking throughout the continent and elsewhere.

The value derived from small Distributed Generation systems e.g. micro grids (fig.4) are no less complex as they introduce logistics problems for systems installations, operations and maintenance O&M and fuel supply in instances where renewable energy sources are not available. Further, their often-small sizes are 'charity sustainable' and can produce a sustainable-strategic dynamic between charities, manufacturers, government agencies, NGOs and universities. A further discussion of the role of universities to provide technical skills and support the development and maintenance of these small systems even while contemplating future grid integration (fig.5) can be found in ref.13.

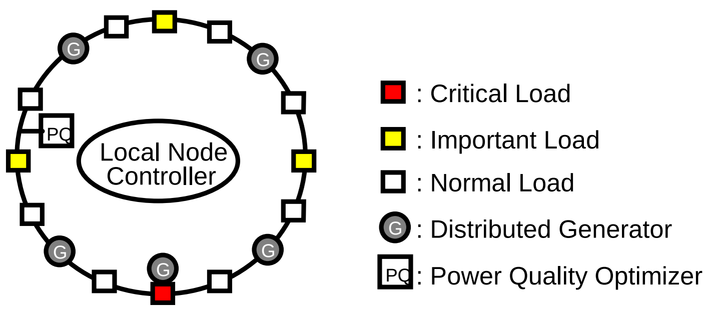

Fig. 4 Formation of Single-Ring Local Node

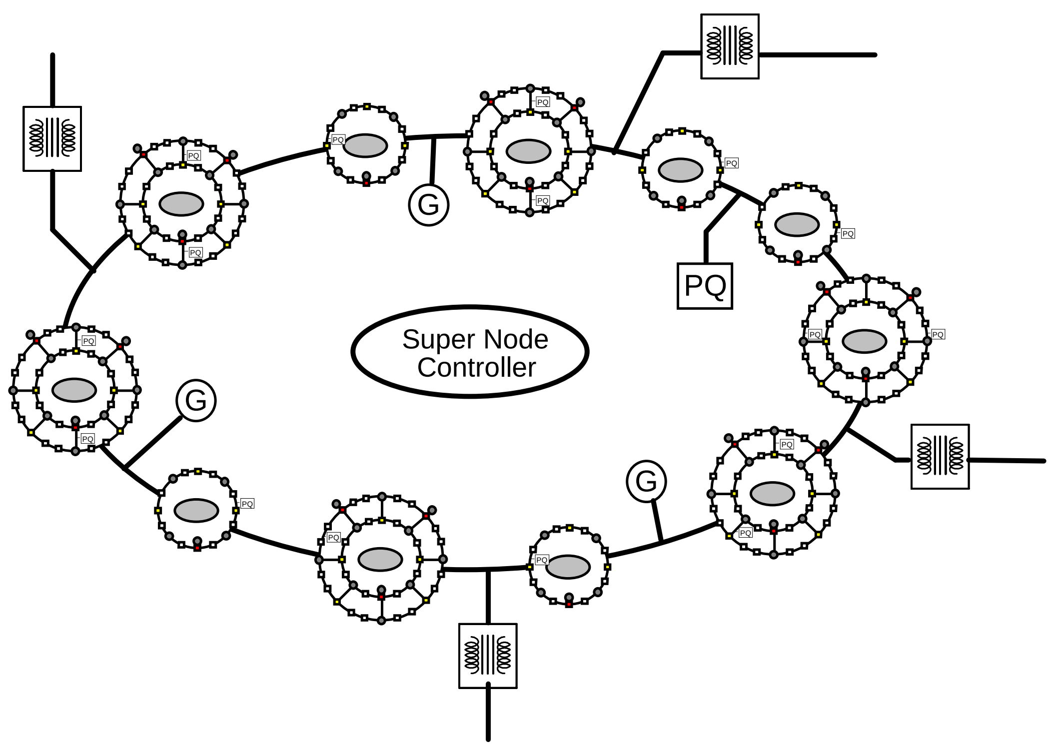

Fig. 5 Formation of a Super Node and Grid Connection

It is instructive to note the following taken from Complex Adaptive Systems, Knowledge, and Systems Management studies ref. 3

As a general rule, we cannot create models that will accurately predict the outcomes of complex systems. We can, however, create a model that will accurately simulate the *processes* the system will use to create a given output. This awareness has profound impacts for economic, organizational, and many other efforts that are concerned with systems of systems that are also of large scale and scope. Most studies of complex systems often run completely counter to the trend toward increasing fragmentation, compartmentalization, and specialization in most academic disciplines. The current trend in complexity studies is to reintegrate the fragmented interests of disciplines into a common pathway. Without a cohesive system ecology to guide development and use of information and associated knowledge, and without the necessary knowledge integration, engineering and management of complex systems is unlikely. Ref. 3

V. THE DYNAMIC PARAMETER MODEL

In the Dynamic Parameter study a "Dynamic Parameter" is an evolved entity abstracted from a selected object that manifests significant information density or convergence in a given sub domain as represented by Fig 6. . The identical nature of the core represents the elements that make up the standardized system dynamics based curriculum. The different backgrounds represent different location contexts.

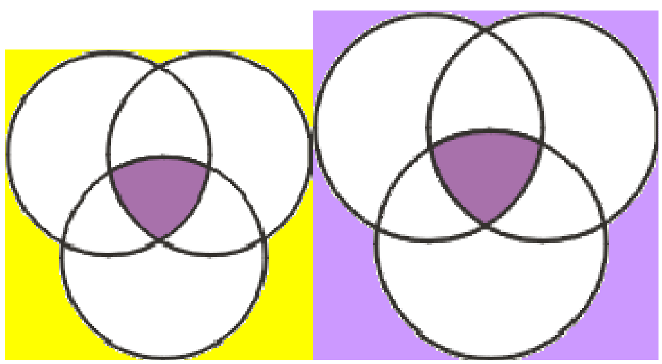

Fig. 6 Dynamic Parameter-Sub Domain relationship

In this instance the object or entity can be a real or projected power plant within one of the power pools being looked at namely the WAPP, SAPP & NAPP. Fig. 7 illustrates a given 'Domain' where the continuous dynamics of relationships are created from knowledge exchange leading to constant flows of feedback.

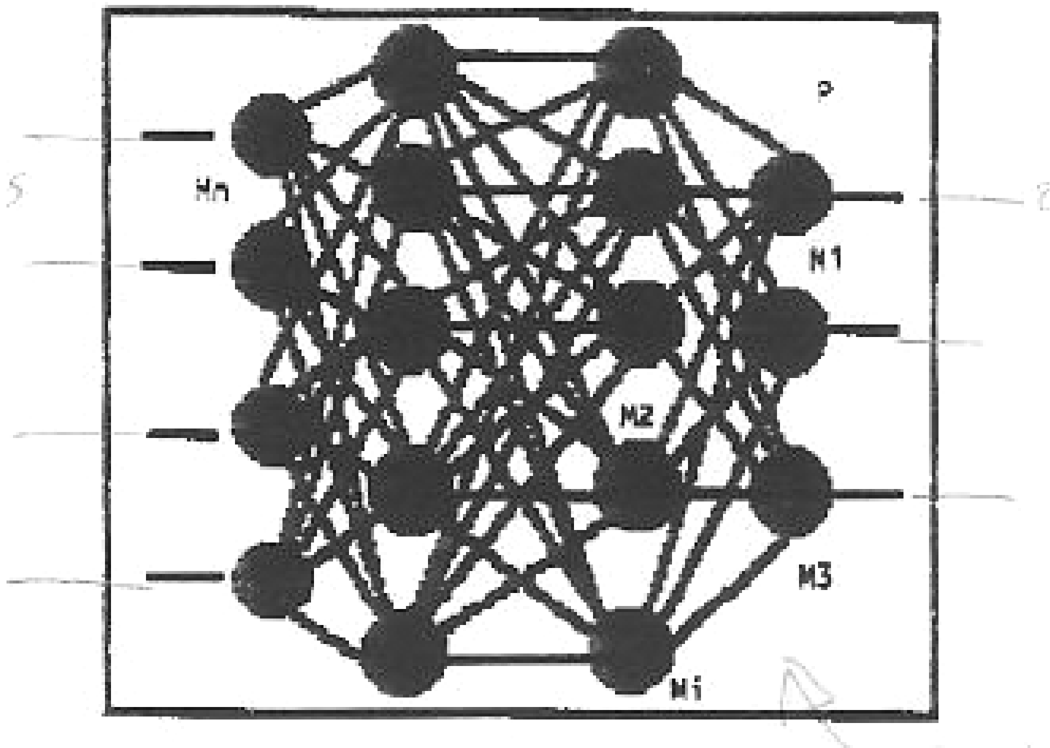

Fig.7 Domain Relationships

VI. CONCLUSION

The creation of communities of practice among African utilities, universities and international institutions while utilizing knowledge from their immediate environment can lead to efficient manpower development. A standardized curriculum carved out to focus on the Energy sector can create a very dynamic talent pool as a result of the variety of domestic and international inputs to the curricula that the systems dynamics feed back process would introduce.

This single focus on the energy sector in the context of institutional integration is sufficient to serve Africa Union (AU) and NEPAD goals by the proposed curricula's ability to produce a broader spread of tertiary level competencies (14) to support the success of these emerging economies while dealing with crisis such as AIDS.

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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 (45 mW) 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 Subcommitee 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 centralised 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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11. CONSIDERATIONS FOR THE PLANNING OF UHVDC SCHEMES IN SOUTHERN AFRICA

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Abstract: This paper describes a simple approach to the planning of long distance electric power transmission systems for Southern African conditions. In common with China and India, significant sources of hydroelectric generation in Southern Africa are situated far form the main load centres. This applies particularly to the single site large hydroelectric resource of 44GW at Inga on the Congo River in the Democratic Republic of Congo and to the more than 100GW distributed sources across Central, West and East Africa.. In all cases, the nearest major load centres are about 3000 to 6000 km away. The salient question is how to reliably and securely transport high power levels of up to 6 GW over this distance. This paper describes the results of the preliminary investigations into developing the transmission master plan for the Western Power Corridor project in Southern Africa.

Keywords: HVAC Transmission, HVDC Transmission, and Hydroelectric Generation

I. NOMENCLATURE

SNEL: Societe Nationale d' Electricite: State Power of Democratic Republic of Congo
ENE: Empresa Nacional De Electricidade: State Power of Angola
SAPP: Southern African Power Pool
SIL: Surge Impedance Loading

II. INTRODUCTION

The Westcor project [1] is intended to exploit the environmentally friendly, renewable, hydroelectric energy of the Inga rapids site in the Democratic Republic of Congo (DRC). SNEL owns and operates the two existing power stations, Inga 1 and 2, with a combined output of 1770MW. Inga 3 is the next phase of the development of the Inga site, with a rated output of 3500MW. Grand Inga would follow this, estimated single site potential is 44000 MW. In addition, ENE of Angola has identified the 6000 MW hydroelectric potential of the Kwanza Basin in northern Angola for development. ENE expressed interest in developing this resource with Westcor and to export the energy to other customers in SAPP. The overall scheme is shown in figure 1. The customers for the energy off take are the participating utilities. The tariff would largely be determined by the overall capital costs. The expectation is world's lowest cost; less than present day levels of 4 US cents/kWh [2].

The project under feasibility study involves:

- The Inga 3 Power Station of 3 600 MW run of the river hydroelectric power generation using 8 turbine Francis of 450 MW each; having a water head of 64,5m and a water flow rate of 5 700 m3/sec.
- Introduction of 500 kV HVAC transmission to interconnect Kinshasa, Inga and Luanda to form the Northern HVAC transmission system of the Angolan and DRC National Grids
- Introduction of two 500 kV – 800 kV – 1200 kV HVDC transmission schemes. Each HVDC circuit will initially operate at 500 kV. A 2 GW rectifier at Inga (DRC), 1,5 GW inverter at Omega (South Africa) and 500 MW tap at Auas (Namibia) will form HVDC bipolar line1. The second line commences

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with a 2 GW rectifier at Kwanza (Angola), 1,5 GW inverter at Pegasus (South Africa) and a 500 MW tap at Gaborone (Botswana). Initial studies show that 2 GW is the maximum power transfer at 500 kV for the given transmission distance at acceptable losses. The fact is that on HVDC any power can be transferred at any voltage; it is just matter of economics how is feasible to transfer for example even 5 GW on 500 kV voltage level. Conductor bundles are becoming in this case huge but manageable. Line as such is becoming more expensive than converter stations. For higher power transfers, higher transmission voltages will be required to further lower power losses and to promote affordable conductor bundles. The first higher option is 800 kV; considered as doable by original equipment manufacturers. In the distant future, 1200 kV could become a practical option. It may be a necessary requirement to engineer, design and construct the transmission line to the highest practical operating voltage level, initially.

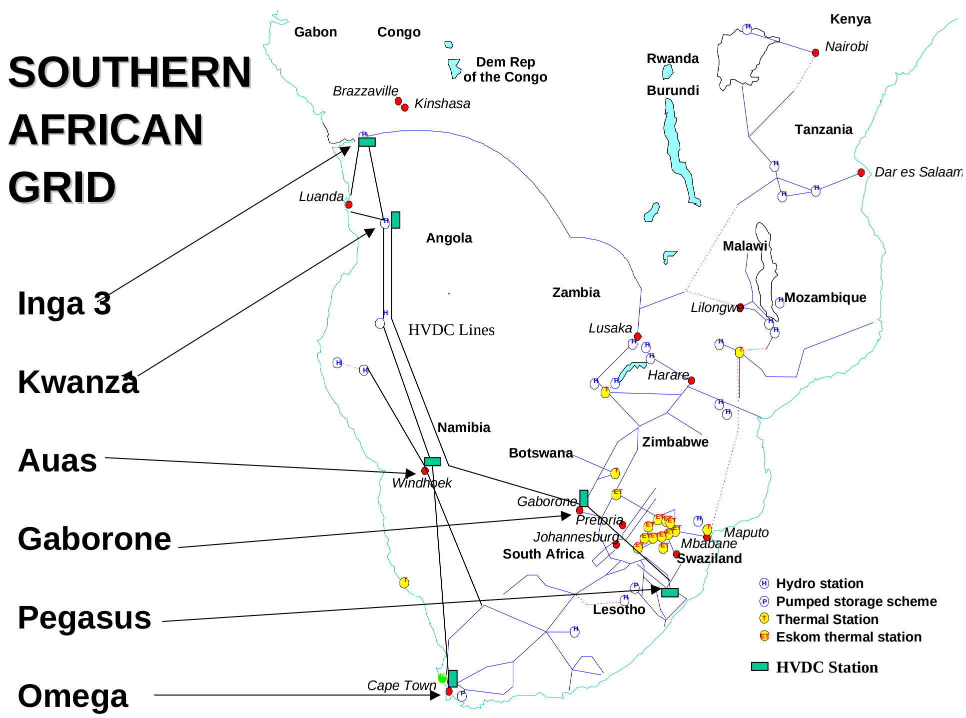


Figure 1. The Western Corridor Power System Interconnecting with the Southern African Power Pool Regional Grid

III. CONSIDERATION OF 765KV HVAC AND HVDC TRANSMISSION TECHNOLOGY

765 kV HVAC transmission is considered a mature and suitable transmission technology that will greatly contribute to the development of the secondary transmission and distribution networks. In Eskom South Africa, two parallel 436km 765 kV transmission lines and a third 765 kV, 281km, line – transformer bank operates successfully. There is no series compensation and only shunt reactors, line and busbar type, are employed to absorb the high unused reactive power generated at times of low power transfer loading.

At 765kV, the six-bundle zebra conductor, of diameter 28,62mm has a current carrying capability of 5152 MVA at normal rating and 6837 MVA at emergency rating. However, due to line charging current and inductive voltage drops, the SIL is 2364 MVA. This difference between installed current carrying capability and SIL is large, appreciable and inefficient. Hingorani [3] has shown that FACTS can be employed to help reduce the inefficiency. Here series compensation, either fixed or variable thyristor switched is possible and can increase the power transfer capability.

Another effective way of increased power transfer capacity through increase SIL is compaction of lines or, in broader sense, implementation of High Surge Impedance (HSIL) concept. This concept was very successfully implemented on Eskom's 400 kV AC lines. One of most characteristic examples is 900-km link between South Africa and Namibia. There is only one intermediate substation on entire length. Similar concept of compaction is now being developed for Eskom's new 765 kV lines [7] and will be introduced on the line between Johannesburg and Cape Town (1500 km)

However, when we consider very long distances, multiples of thousands of kilometers, 3000 km – 4000 km, the benefit is marginal. Here we note that so called half-wave concept for AC transmission on the distance of about 3000 km is still considered not enough and not well investigated to be anticipated as a practical option [7].

The whole chapter of transmission hands over the task to that of HVDC technology, whereby line charging currents and inductive voltage drops go to zero and only the DC series resistance becomes the constraint to power flow. This is demonstrated by using the results of a parallel study to recycle and upgrade HVAC lines for HVDC application currently in progress at Eskom, South Africa. For the transmission line, one phase conductor bundle is configured as a positive pole, the middle phase conductors as metallic-earth return and the remaining conductor bundle as the negative pole of the DC circuit.

This study involves the investigations into the upgrading and converting HVAC transmission lines for HVDC application for cases where the unused power transfer gap is very large and appreciable. Initial, additional and final boundary conditions were introduced for the development of the engineering solution, [4], [5], [6]. One interesting observation made is that to increase SIL, the strategy is to increase either the operating HVAC voltage or to reduce the characteristic impedance Zc. We find that with increasing operating voltage, the corresponding inefficiency of unused conductor current carrying capability also increases. This implies that there does exist at some point an economic and technical limit to higher HVAC transmission voltages. This is not the case for DC. In the case of DC, series resistance power loss dominates and nominal current is limited for acceptable levels of losses; the higher power transfer duty is passed onto higher operating voltages.

Case Study 1: Short Line Model: Eskom's Alpha to Beta 436km 765 kV HVAC Transmission Line

- The equivalent total resistance Rt. is 4,9 ohms [436 km x 0,0674 ohms/km = 29,38 ohms; for 6 parallel conductors; 1/Rt = 6/29,38 ohms; Rt. = 4,9 ohms] and the nominal current carrying capability is 6 x 860 = 5160 amps.
- Voltage Drop per pole = 25,28 kV
- Power Loss per pole = 130,5 MW
- Power Transfer @ 400 kV operating voltage = 2064 MW per pole
- Power Transfer @ 500 kV operating voltage = 2580 MW per pole; just above the SIL of 2364 MVA
- Power Transfer @ 600 kV operating voltage = 3096 MW per pole
- Power Transfer @ 700 kV operating voltage = 3612 MW per pole
- Power Transfer @ 800 kV operating voltage = 4128 MW per pole
- Total Power Transfer per bipole = 4128 MW @ 400 kV and up to 8256 MW @ 800 kV

Total losses per bipole = 261 MW; 6,3 % of received power @ 400kV; 3,2% of received power @ 800 kV
Total sending end power = 4389 MW @ 400 kV and 8517 MW @ 800 kV.

Technical Summary: For the short transmission line model, an existing HVAC 765 kV line can be recycled and upgraded to HVDC technology; to carry its SIL at a lower operating voltage. At higher operating voltages; to carry twice as much as its SIL with lower power loss.

Case Study 2: Medium Line Model: Here we increase the line length to 1200 km so as to represent the full distance from Alpha substation to Koeberg Nuclear station outside Cape Town

- Equivalent resistance Rt = 13,48 ohms [1200 km x 0,0674 ohms/km = 80,88 ohms; for 6 parallel conductors; thus 1/R = 6/80,88 ohms; R = 13,48 ohms] and the nominal conductor current carrying capability is 6 x 860 = 5160 amps..
- Voltage Drop per pole = 69,6 kV
- Power Loss per pole = 358,9 MW

For the next few calculations, we note that the total power transfer per pole is the same as for the short line model of 436km; implying that the calculation is independent of distance. The similar will apply for the long line model; this is a main characteristic feature of DC transmission where the current levels and power transfer levels can be set by choice and design.

- Power Transfer @ 400 kV operating voltage = 2064 MW per pole
- Power Transfer @ 500 kV operating voltage = 2580 MW per pole; just above the SIL of 2364 MVA
- Power Transfer @ 600 kV operating voltage = 3096 MW per pole
- Power Transfer @ 700 kV operating voltage = 3612 MW per pole
- Power Transfer @ 800 kV operating voltage = 4128 MW per pole

Total Power Transfer per bipole = 4128 MW @ 400 kV and up to 8256 MW @ 800 kV
Distance now enters the calculations and impacts on power loss and sending end power totals

- Total losses per bipole = 717,8 MW; 17,4 % of received power @ 400kV; 8,7% of received power @ 800 kV
- Total sending end power per bipole = 4845,8 MW @ 400 kV and 8973.8 @ 800 kV.

Technical Summary: Increasing the transmission voltage has the effect of reducing the power loss as a percentage of received power. For the medium line model, at nominal current loading, 800 kV is the required voltage. The lower voltages result in higher power losses. Alternatively, the option could be to reduce the nominal current but simultaneously for us to consider reducing the size of the conductor bundle if a new line is planned. For example, if we lose 2 conductors, then for a 4-conductor bundle operating at 600 kV; we have 833 amps on an 860 amp rated zebra conductor for a 4000 MW bipole. Power losses will be of magnitude 20,22 ohms x 3332 amps x 3332 amps = 224 MW; 5,6% on total received power of 4000 MW at 600 kV. At 800 kV and assuming that a 4 bundle conductor configuration would be adequate for electric field and corona effects; the loss percentage reduces to 3,1 % (126,4 MW). From these simple calculations and analysis, it is clear that HVDC is the choice for GW power transmission at the higher operating voltage. The 1200-km distance is not a key parameter of interest; it only contributes to power loss and voltage drop calculations. The justification for that higher DC operating voltage is reduced power losses.

Case Study 3: Increasing the line length to 4000 km so as to represent the full distance from Inga Power Station in the Democratic Republic of Congo and to Omega substation outside Koeberg Nuclear station at Cape Town

- The total equivalent resistance Rt. goes to 44,93 ohms [4000 km x 0,0674 ohms/km = 269.6 ohms; for 6 parallel conductors; thus 1/R = 6/269.6 ohms; R = 44,93 ohms] and the nominal current carrying capability remains at 6 x 860 = 5160 amps.
- Voltage Drop per pole = 231,83 kV
- Power Loss per pole = 1196,29 MW. This is very high and clearly current has to be limited given the high series DC resistance. For a 4-bundle configuration, resistance increases to 67 ohms and nominal current reduces to 3440 amps. Power loss is then calculated to be 792,8 MW. This is still substantial and current needs to be further reduced to say 2500 amps; yielding power loss of 418,7 MW. Further reduction of current to 2000 amps will yield a power loss of 268 MW. We have now reduced the bundle to that of 3 conductors and total resistance increases to 90 ohms; total power loss = 360 MW.

For the next few calculations, we recalculate the total power transfer per pole as at 2000 amps ;

- Power Transfer @ 400 kV operating voltage = 800 MW per pole
- *Power Transfer @ 500 kV operating voltage = 1000 MW per pole*
- Power Transfer @ 600 kV operating voltage = 1200 MW per pole
- *Power Transfer @ 700 kV operating voltage = 1400 MW per pole*
- *Power Transfer @ 800 kV operating voltage = 1600 MW per pole*
- *Power Transfer @ 1200 kV operating voltage = 2400 MW per pole*

Total Power Transfer per bipole = 1600 MW @ 400 kV and up to 3200 MW @ 800 kV and 4800 MW @ 1200 kV.

Summary: For the long line model, we set the acceptable levels for power losses and gradually reduce the conductor bundle order. On the reverse, we promote a higher operating voltage for higher power transfers and when electric fields and corona effects are considered, the bundle order would need to be increased. These are design controlled and if the power line is made as high as possible, then such effects if present, would not impact on the population at ground level. Having concluded on HVDC technology for higher power transfers over longer distances; we now seek the environmental input into the power line design.

IV. FIRST INPUT FOR TRANSMISSION LINE DESIGN

Higher voltage DC transmission and run of the river hydro-generation would be new engineering focus areas involved in this project. The project has been presented to major manufacturers and the conclusion is that the scheme is doable. The challenge will be to prepare the lowest cost engineering solutions such that the delivered energy contributes to sustaining the regions competitive edge of having the world's lowest cost electrical energy [2].

From a planner's perspective, four key variables must be considered; voltage, conductor size, current rating and configuration, required power transfer capacity, including the impact on system stability arising from interruptions, and the external environment such as topography, climate and altitude. Voltage is affected by the availability of proven technology and a way forward could be to prepare an evolutionary modular design whereby voltage is increased when loading increases.

First pass transmission line servitude route selection using satellite technology shows that innovative and creative transmission line engineering would be required if environmentally induced transmission line faults are to be avoided. Simultaneously, the engineering designs must be prepared to achieve the least impact on the environment.

Using satellite applications photography, we record that multiple DC circuits would need to be packaged into the least number of servitudes. The Western region of equatorial and tropical Africa is home to many waterways, lakes and pans; all rich with fauna, flora and wildlife. An absolute minimum infrastructure footprint is recommended. The optional routes are shown in figure 2 and one could conclude that the options are limited. It is best for the proposed transmission servitude route to follow the existing road networks and settled corridors through the five countries.

Further, it will also be necessary to carry multiple circuits in just one servitude; the downside being higher heights and higher probability of line exposure to lightning faults and total loss of transmission in the event of tower structural failure. Typical transmission line faults will include lightning, servitude fires, trees in servitude, hardware failure, external insulation failure, and bird dropping onto external insulation and into electric filed stressed air gaps. It may be possible that by using height, one could avoid many of the ground based environmental faults. To manage the lightning challenge, we use all the insulation co-ordination strategies and solutions, including high-speed converter control to self heal the transient lightning faults.

The possibility also has to be considered of de-rating the line capacity (reducing the voltage) under conditions that increase the risk of an event. For example, operating voltage could be reduced in the presence of fires, rain or lightning along the length of the line provided that intelligent condition sensing was available.

The risk (reliability) of a line would be extrapolated from that for other lines operating in the same environment. Thus, raw fault or reliability data from other installations needs to be modified for application to planning alternatives.

Given the extra long distance for transmission, it will not be practical to conduct servitude clearing and maintenance. Once again, the extra height requirement of the tower could help contribute to this practical constraint. In addition, visual pollution will also be reduced as longer spans is possible with higher towers and the conductors will appear to be invisible and beyond the horizon. J.A.T. Gillespie reported this: Design and Maintenance of Insulation for a North Queensland transmission line, paper 400-9, Cigre Symposium, Cairns 3 –7 September 2001.

In summary the transmission line input design parameters would be as follows:

- The design must reduce to its minimum servitude maintenance such as cutting and clearing of natural vegetation such as trees and shrubs;(in some areas – subtropical part – will be extremely difficult, if possible at all to go over existing vegetation, very high and dense forest, DM).
- The design must make allowance for full scale live line maintenance technologies, due to long distances and rather insufficient infrastructure along route(s).
- The design must allow for the presence of servitude fires such that no air gap breakdown occurs between pole and earth or between multiple circuits;
- The land footprint must be optimized so as to allow for continued land use such as undisturbed natural ground or commercial farming etc and the presence of the line has no effect on the normal wild

life movements.

- The design must cater for bird flights and bird landings including bird droppings onto the external insulation and into energized air gaps

Westcor Proposed Routes

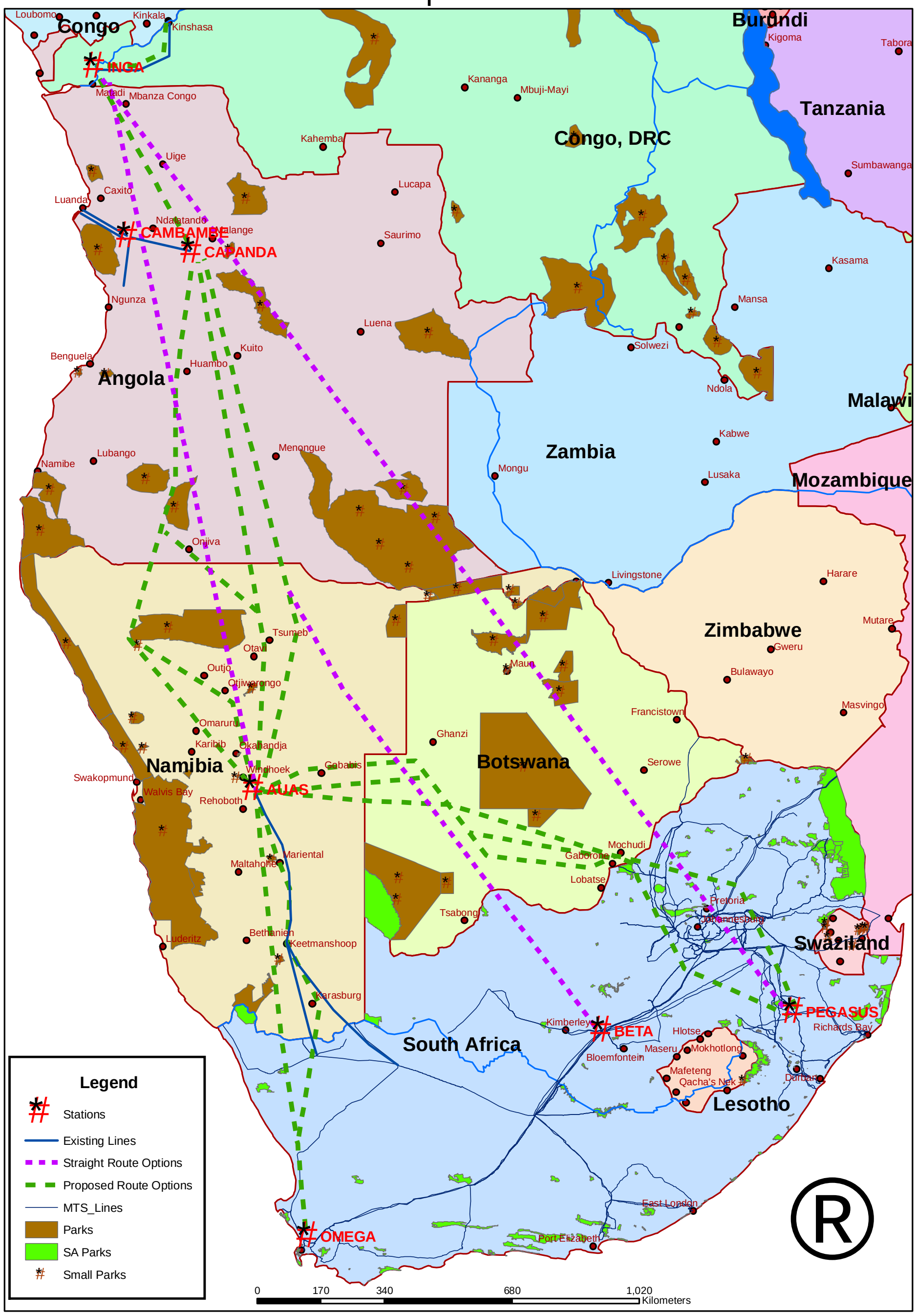


Figure 2. Optional Routes for Transmission Line Servitudes.

For line development, Eskom's present thinking is to exploit the excellent experience gained with the development of compact AC lines. Based on this, one very intuitive proposal to be offered will be a cross-rope type structure for a bipolar ± 800 kV line, such as the conceptual design shown in Fig. 3.

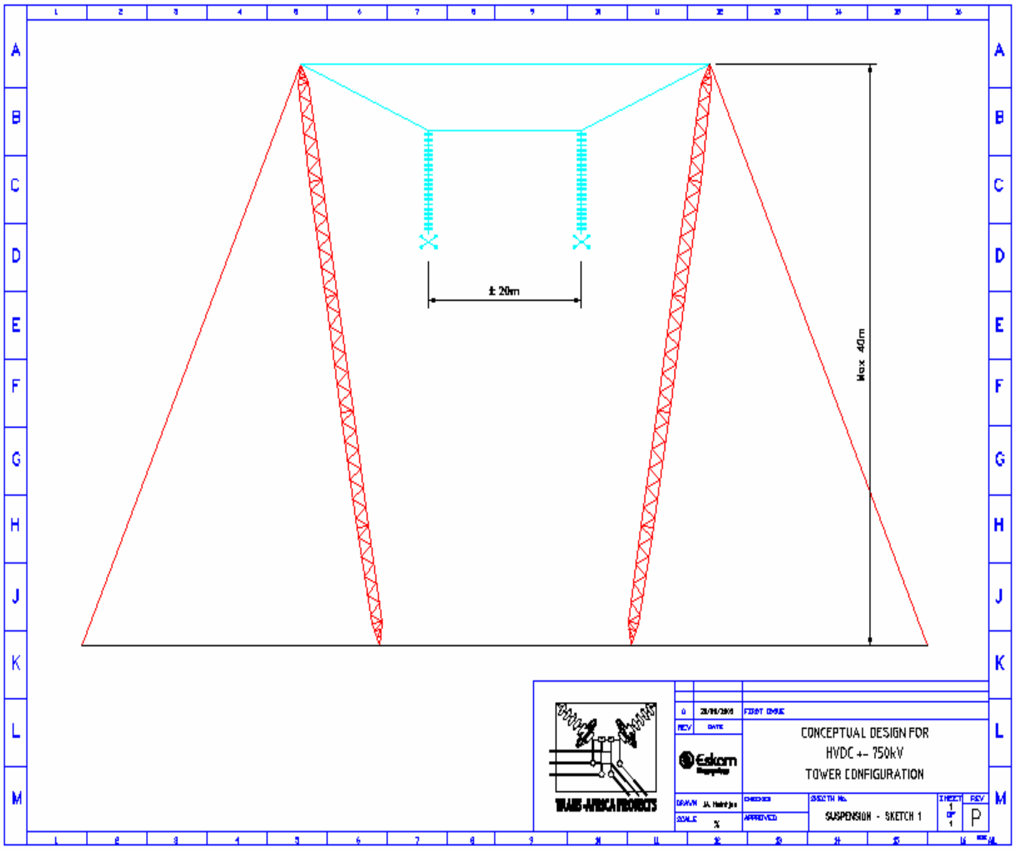
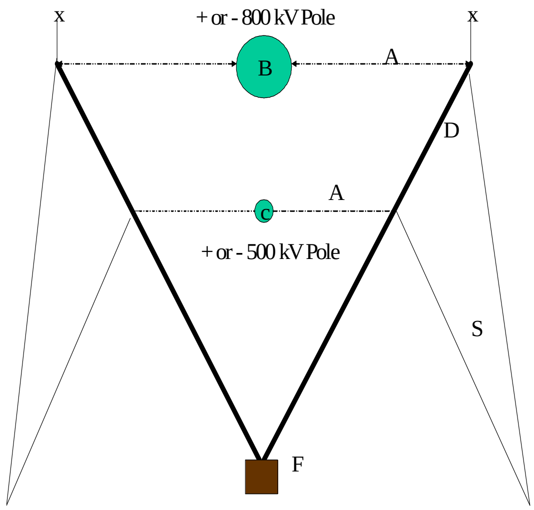


Fig. 3. ± 800 kV HVDC tower concept

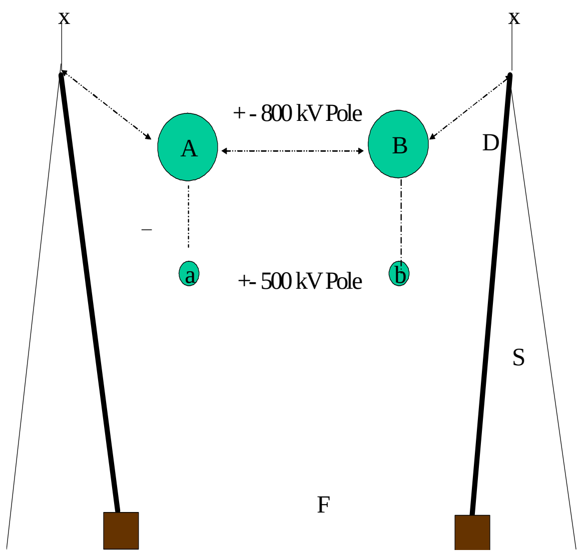
The requirement to reach the highest power transfer capability along specified corridors leads to the development of multi–pole multi circuit line configurations. This concept can be used effectively when we have to carry two HVDC lines with different voltages or, if we have to carry on the same structure HVDC line an AC line (for regional AC network for example. Here we will have an elaborate option of two monopole lines on the same structure and example of two bipolar lines with different voltages (800 and 500 kV).An artist impression of a composite monopole design is shown in figure 4-a. Figure 4b presents the same for bipolar lines example**.**

Guyed 400 kV and 765 kV structures have been successfully engineered by Eskom and in general the historical performance have yielded a lower cost design with zero permanent structural failures. The probability of the loss of the entire multiple pole structure approaches zero and thus the confidence to promote the shared scenario in lieu of reduced servitude requirements.

The presence of the 500 kV circuit is in support of on route tap off (for multi terminal DC operations) whilst the 800 kV is engineered more for point to point bulk transmission. Further, the structural engineers could make up the design in modular such that the 800 kV section could be added at a later date when the higher volume hydroelectric generation is ready for evacuation. Alternatively, IGBT technology makes possible large power taps at the higher voltage. The complete powerline can be initially built at 800 kV or 1200 kV and the terminal converter upgrades can be prepared in modular design to grow with increasing demand and supply. At 800 kV or 1200 kV DC, air and silicone coated toughened glass disc insulators contribute to a lower cost outcome if employed ahead of time.



a) Two monopolar solution ;



b) two bipolar solution

Figure 4. An artist impression of a composite 500 kV and 800 kV positive or negative polarity pole as a guyed structure.

Here the symbols refers to:
A – External Insulation Composite Assembly, including insulator with guyed steel ropes; B – Extra high voltage (800 kV) DC pole arranged in either 6 to 8 conductor bundles; C – High Voltage (500 kV) DC pole arranged in either 4 to 6 conductor bundles; D – Steel work for the Guyed Structure; X –Earthwire Point of Attachment; S – Guyed structure steel staywires; F – Pivot Foundation

V. CONCLUSION

The Western Power Corridor calls for new and innovative thinking. The engineering solutions are required so as to yield both a lower capital cost with a lower environmental footprint. Environmental engineering should provide the first input parameters for the design process. The lower capital cost expectation is driven by the need to preserve Southern Africa's competitive edge of world's lowest cost electricity. In the case of Westcor, there is no direct cost for the primary energy source. The tariff for energy delivered will be based on the capital costs of the project and the cost of operating and maintenance.

The project is planned and promoted such that the profit margins will be the smallest whilst the energy volumes the largest. Southern Africa is in need of electrons that will actively support the economic renaissance of the region and the continent. This planning strategy further promotes a lower per unit cost when volumes are simultaneously increased. The Congo River has capacity to deliver higher volumes and the 800 kV DC transmission can evacuate the higher loads. In our first pass DC study, we noted that the power electronics employed would have a thermal capability of 6GW per circuit; an encouraging outcome. However, as a feed into an HVAC grid with 40 GW of load, the reliability and stability consequent on loss of a 6 GW feeder would be problematic. Using a 10% import level against a 15% reserve margin system level; a 6GW injection would only be realised when the system total is 60 GW. For the present day, lower levels of transfer would be promoted but with the option to upgrade when required. DC lends itself to such modular upgrade. The ideas presented would be further explored during the pre-feasibility phase of the project engineering.

The recommendations for State Grid and Eskom South Africa is to consider the application of HVDC technology as suited for bulk power handling; for higher power transfers over longer distances. The extra high [800 kV] and ultra high [1200 kV] voltages have their own motivation as in higher power loss savings coupled with the modular design strategy such that the next stage of higher voltage is achieved at minimal cost; provided that the transmission line is initially engineered creatively for next higher voltage of application..

765 kV HVAC should be limited for special applications in the case of short to medium length transmission line models. 500 kV HVAC is a suitable voltage for power distribution / power delivery; optimum sizes could be in the order of 400 to 600 kV; with series compensation. Theoretically, Padiyar [8] summarised that the economics of transmission, the technical performance and the reliability of transmission determine the relative merits of AC and DC. Whilst DC has higher terminal equipment costs, the line requirements are less onerous and over larger distances, these would balance and cancel out of the debate. DC then emerges the choice as it takes full control over power transmitted, it has the ability to enhance transient and dynamic stability in associated AC networks and enhances quality of supply delivered by attenuating fault current by fast control. This results in no voltage dips for line faults.

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12. EVALUATING AUTONOMOUS SYSTEMS WITH HYBRID GENERATION FACILITIES IN SUPPORT OF FISHING VILLAGES (PAPER 07GM1327).

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Abstract: 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. 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. In addition to regional cooperation and integration through energy pooling and cross-border energy trading, a balanced Distributed Generation strategy through modified micro grids has been proposed in the previous discussion [1]. This paper serves as continuation of a distributed micro grid application specific to small towns and villages fishing processing potential. 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.

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1. INTRODUCTON

The NEPAD Action Plan for the development of African Fisheries and Aquaculture initiated in August 2005 in Abuja, Nigeria highlighted the importance of this industry to the direct incomes of 10 million people and contributing to the food supply of 200 million. more. In certain countries such as Uganda fishing makes a significant economic contribution. For example, lake fisheries yield catches worth more than $200 m a year, contributing 2.2 per cent to the country's gross domestic product. They employ 135, 000 fishers and 700,000 more in fish processing and trading, and generate $87.5 m in export earnings.

Overall, African Fish exports increased notably during the 19080s and 1990s.By 2001 they reached a value of $2.7 billion –about 5 per cent of the total global trade of $56 billion. According to the UN Food and Agriculture Organization (FAO), fish products make up more than 10 percent of the total value of national exports in 11 African countries.

Several cautionary flags were raised at the conference as it related to the consequences of collapsing fish stocks and the human consequences if not sustain ably managed and the impact of encroachment by foreign vessels resulting in over-fishing. One other important recommendation to support sustainable aquaculture was the need for various forms of infrastructure. In both coastal and inland fisheries, these would include landing sites, cold units, road and transportation systems and marketing facilities. A previously stated this paper will discus a supporting energy infrastructure made of a complement of hybrid technologies most likely to be found in around fishing villages and the optimization of their operations.

II. FISH PROCRESSING

The fish processing industry is very widespread and quite varied in terms of types of operation, scales of production and outputs. Marine fish account for more than 90% of fish production, with the remainder being fresh water fish and fish produced by aquaculture. In general, fish processing operations are located close to commercial fishing areas. Approximately 75% of world fish production is used for human consumption and the remaining 25% is used to produce fishmeal and oil. Fishmeal is a commodity used as feed for livestock such as poultry, pigs and farmed fish and fish oil is used as an ingredient in paints and margarine.

Currently, only about 30% of fish produced for human consumption are marketed fresh. The supply of frozen fish fillets and fish, in the form of ready-to-eat meals and other convenience food products is growing in both developed and developing countries.

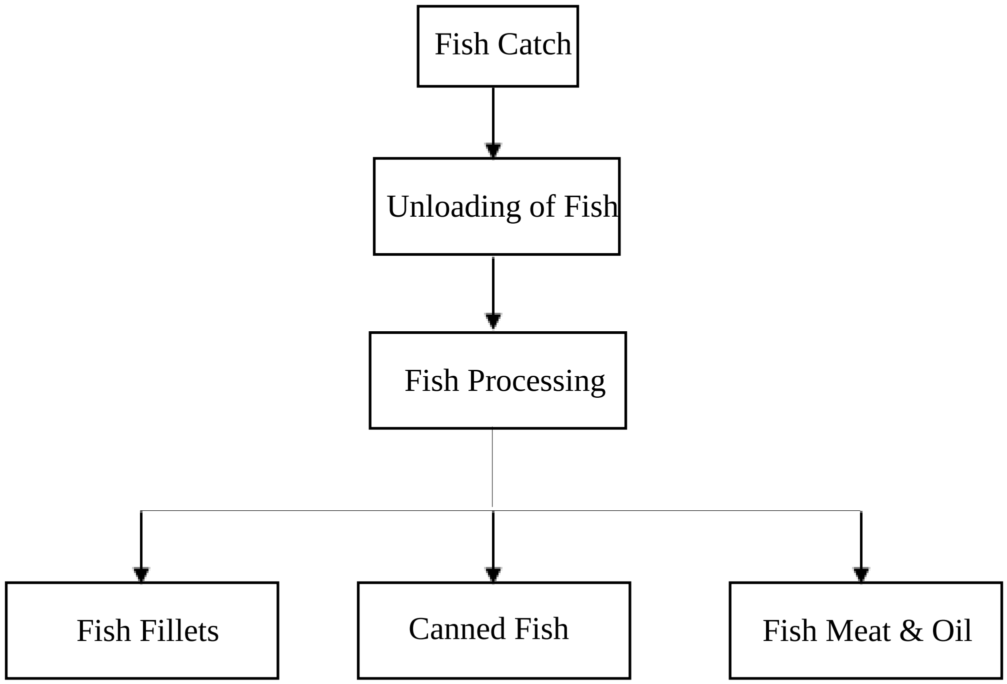

Figure 1. General Flow Diagram for Fish Processing

The general schematic in Fig.1 provides an overview of all forms of fishing and fish processing and is important for designing optimum energy supply solutions to specific needs. Many of these processes lend themselves to cogeneration applications utilizing small engine driven DGs with a hot water loop or high efficiency absorption chillers that can achieve refrigeration temperatures with low grade heat less that 200°F such as the Thermosorber™ Other non engine renewable sources that make up hybrid systems are discussed in preceding paragraphs.

II. ENVIRONMENTAL IMPACTS OF FISH PROCESSING

As for many other food processing operations, the main environmental impacts associated with fish processing activities are the high consumption of water, consumption of energy and the discharge of effluent with a high organic content. Noise, odor and solid wastes may also be concerns for some plants.

Water Consumption: Fish filleting and canning processes consume very large quantities of fresh water. Water is used for transporting fish and offal around the plant in flume systems, for cleaning plant and equipment, for washing raw materials and product, and for de-icing and thawing.

For fish meal and fish oil production, sea water is typically used for cooling and condensing air from the evaporators and scrubbers, and comparatively minor quantities of fresh water are used for the centrifuges, for producing steam and for cleaning.

Energy Consumption: Energy is used for operating machinery, producing ice, heating, cooling, and drying. Production of fishmeal and fish oil requires significant amounts of energy for cooking, drying and evaporation. Depending upon the source of energy, the consumption of energy may also produce air pollution and greenhouse gas emissions.

Effluent Discharge: Effluent streams generated from fish processing contain high loads of organic matter due to the presence of oils, proteins and suspended solids. They can also contain high levels of phosphates and nitrates. If the effluent streams are discharged without treatment into water bodies, the pollutants they contain can cause eutrophication and oxygen depletion.

Table 1 contains water usage, wastewater, energy consumption, and solid waste for each of the processes for fish processing. The values are representative of average technology. The information is derived from Danish plants, and from a few African and American plants. They should be used with care, due to the processing variations discussed above. Rates of resource consumption and waste generation can be much higher than stated in this section.

Table 1 Resource Consumption and Waste Production of Fish Processing (per 100 kg)

<table>
<tr><th rowspan="2"></th><th colspan="2">Water (m^3)</th><th rowspan="2">Waste Water (m^3)</th><th colspan="3">Energy (KWH)</th><th colspan="3">Solid Waste (Kg)</th></tr>
<tr><th>Sea</th><th>Fresh</th><th>Ice</th><th>Freezing</th><th>Filleting</th><th>Skin</th><th>Head</th><th>Bone</th></tr>
<tr><td>Filleting of White Fish</td><td>N/A</td><td>5 / 11</td><td>5 / 11</td><td>10 / 12</td><td>50 / 70</td><td>5</td><td>40 / 50</td><td>210 / 250</td><td>240 / 340</td></tr>
<tr><td>Filleting of Oily Fish</td><td>N/A</td><td>5 / 8</td><td>5 / 8</td><td>10 / 12</td><td>50 / 70</td><td>2 / 5</td><td colspan="3">400 / 450</td></tr>
<tr><td>Canning</td><td>N/A</td><td>15</td><td>15</td><td colspan="3">150 / 190</td><td colspan="2">250</td><td>100 / 150</td></tr>
<tr><td rowspan="2">Fish Meal and Oil Production</td><td rowspan="2">20</td><td rowspan="2">0.5</td><td rowspan="2">21</td><td colspan="2">Electricity</td><td>Fuel Oil</td><td colspan="3">Water Vapor (Kg)</td></tr>
<tr><td colspan="2">32 KWH</td><td>49 L</td><td colspan="3">600 - 700</td></tr>
</table>

III. PROPOSED AUTONOMOUS ELECTRICAL SYSTEM

Today, less than 15% of Africa's population has access to electricity with much of the available supply being unreliable. In addition, there are wide disparities in access to electricity. For example, up to 67% of South Africans have access to electricity (Karekezi, 2003) while only 6% of Malawians have access to electricity (Potani, 2002) and in Lesotho, about 4% of the population has electricity. Similar situations are observed in different regions. Therefore, local electrification will have direct benefit to the residents. Regarding the resource to generate the electricity, one should harvest the local resources with minimum impact to the environment. A hybrid system with the following generating facilities should be considered first in the rural electrification process:

Run-of-River Hydro Generation: Run-Of-River hydro projects can be any size. Generally though, small and micro-hydro projects are the primary type of Run-Of-River hydro system. Run of river hydro systems can provide power to homes, farms and small commercial businesses just like other type of generators.

Before considering a micro hydro system, the site must have a sufficient volume of falling water, usually in the form of a creek. From an environmental perspective, a general recommendation is that no more than 20 - 50 percent of a creek's flow should be diverted for a micro hydro system. Since there are lots of rivers flowing in the Africa continent, this should be one of the most favorable technologies for the African community. The following simple equation estimates power output for a system:

*Net Head (ft) * Flow Rate (cfs)*conversion factor = Generated Power (KW)*

where

The conversion factor should take hydraulic loss, turbine efficiency, and generator efficiency into consideration (typical value: 0.0864).

System capacity may be dictated by specific circumstances (e.g. water dries up in the summer). If insufficient potential is available to generate the power necessary to operate the average load, one must add other forms of generation equipment to the system. Hybrid wind/solar photo-voltaic/hydro/geothermal and biomass are very successful and the energy sources complement each other.

Biomass Energy: Converting biomass energy into useable energy 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. A brief description of each type of biomass is provided below:

- ***Agricultural residues****:* They are generated after each harvesting cycle of commodity crops. A portion of the remaining stalks and biomass material left on the ground can be collected and used for energy generation purposes. For example, residues of wheat straw, rice husk, and corn stover are ideal for biomass generation. Effluent streams generated from fish processing contain high loads of organic matter due to the presence of oils, proteins and suspended solids. They can also contain high levels of phosphates and nitrates. Through proper process, they can produce methane and be used for power generation. In addition, In addition, 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.
- ***Energy crops****:* Some plants are produced solely or primarily for use as feedstock in energy generation processes. Energy crops include hybrid poplar, hybrid willow, and switch grass.
- ***Forestry residues:*** Timber harvesting operations do not extract all biomass material, because only timber of certain quality is usable in processing facilities. Therefore, the residual material after a timber harvest is potentially available for energy generation purposes.
- ***Urban wood waste/mill residues****:* The urban wood waste/mill residue category includes primary mill residues and urban wood such as pallets, construction waste, and demolition debris, which are not otherwise used.

For Africa, agricultural residues will be the main resource for the biomass energy development.

Solar Energy: Solar energy is light and heat energy from the sun. One can either use solar cells (photovoltaic) or solar thermal technology to produce electricity.

The continent of Africa has 15% of the world land area and extends from about the 35^o north of the equator to about the 35^o south of the equator. It is an ideal location to develop and use solar energy.

Wind Energy: Wind energy has gained an extensive interest and become one of the most mature renewable energy. The development of wind electricity generation has rapidly progressed over the last decade. The record shows that wind power generation has expanded with annual rate of 25 percent since 1990 and has a great potential to be realized in many regions of the world. The coast areas in Africa have good potential to use wind generators.

IV. OPERATION CONSIDERATIONS OF AN AUTONOMOUS SYSTEM

The impact of disturbances during autonomous operation is very important since islanding system is a weak system. Large motor starting, load following, and load rejection, create significant impacts on the performance of the islanded system and should be studied.

Large Motor Starting: There are lots of motors, compressors in the fish processing plant. They will be turned on and shut down according to the operation requirement. During the start-up period, they will cause voltage sag for a short period because of the high starting current (2-4 times of rated current) with low power factor when starting a large induction motor. The level of voltage sag depends on the stiffness of the system. Since the islanding system is relative weak, the effect of starting a large motor requires further investigation.

Load Following and Load Rejection: It is normal that the electric energy demand of the fish processing plant does not remain constant. The load following/rejection capabilities of DGs affect the system performance during operating at islanding mode.

Dynamic Performance: Fault is a severe disturbance occurring in the system. System may still experience various fault conditions during islanding operation. It is important to ensure that system (both DGs and customers) is proper protected when a fault occurs during islanding operation.

V. REALIZING THE PROPOSED CONCEPT

The proposed microgrid systems are designed in a modular fashion so that they can be reconfigured and expanded easily Fig.2 according to the size, need, and available sources of the fishing villages. This feature is indispensable for successful multiple deployment. However, taking ownership of the local community is the key to the success of the proposed program.

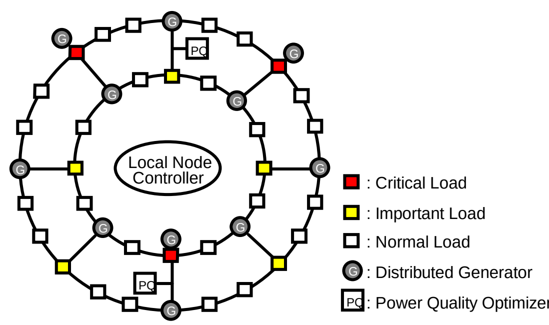

Figure 2. Formation of Double-Ring Local Node

The following lists the key players for the whole process:

- Obtain initial commitment from those institutions and foundations such as World Bank, United Nations, foundations, The HIP HOP Nation, and ONE.org that represent different levels of sponsorship to the proposed development.
- With the help of national and international experts, local governments and communities should present the initial plans. The plan should include the approaches to use the electricity for sustainable local economy development.
- Local government, utility, and communities should agree to gradually assume the responsibility by either interconnecting the local grid with the main system (if applicable) or providing the necessary financial and technical support to operate the system continuously.
- External sponsorship could then be phased out in five years or less (20% reduction per year).
- A Teacher-Train-Teacher (T^3) program should be established. National and international experts will train the faculty members at local universities/technical schools the necessary skill for operating and maintaining the system. The university bodies and technical schools throughout particular regions or

from within the AU could then be seen as incubators for creating “Energy Peace Corps” trained to service and manage these systems.

VI. CONCLUSION

The availability of affordable and reliable energy remains one of the most crucial requirements for economic development and modernization of developing countries. Without any doubt, electricity is among the top priorities to achieve minimum effective sustainability. Since Africa is surrounded by Indian and Atlantic Oceans, and the marine fish account for more than 90% of current fish production. There is great potential for developing fish processing industries.

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