PANEL SESSION: AFRICA---INTEGRATED GAS AND ELECTRICITY TRANSMISSION PLANNING IN POWER GENERATION AND ENERGY DEVELOPMENT BENEFITS, AND DEVELOPMENTS IN HVDC ENGINEERING TECHNOLOGY IN HARNESSING LARGE-SCALE HYDROELECTRIC SITES FOR INTERCONNECTED REGIONAL POWER SYSTEMS

(Tom Hammons, Pat Naidoo and Bai Blyden)

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

Topic: Integrating New Sources of Energy in Power Systems

INTRODUCTION

This Panel Session will discuss integrated gas and electricity transmission planning in power generation and energy development with their benefits, and developments in HVDC Engineering Technology in harnessing large-scale hydroelectric sites for interconnected regional power systems.

This years panel session, as with previous sessions, focuses on integrated gas and electricity planning, the present status and future prospect of electricity infrastructure from the viewpoint of generation and transmission development, policies and lessons from global deregulation, advances in global research, and development (R&D) and strategies to influence Africa's integration into the Global transition to knowledge-based economies.

Panel presentations will focus on regional power pool examination as an economic development paradigm by emphasizing the systems effects that lead to improving economical, ecological and technological efficiencies by the joint operation of power systems. The examination of these models remains core to the strategies presented under these panel sessions because of the focus they can provide to influence wider institutional integration and in particular academia where core mathematical and technical skill sets necessary for building knowledge-based economies are developed.

Document prepared and edited by T J Hammons

Active projects such as the Westcor project representing an initial phase of the large regional South African Power Pool will showcase new milestones in HVDC technology used to harness the large hydro potential contributing to the pool. Presentations from CIGRE's activities in Northern Africa and the West African Power Pool's central high voltage transmission trunk development by the World Bank will also be made.

The Panelists and Titles of their Presentations are:

1. Ahmed Faheem Zobaa, Cairo University, Egypt and Pat Naidoo, Senior General Manager of Transmission Company, ESKOM, Johannesburg, South Africa. Electric Power Development and Trade, and Power Sector Reform in Africa (paper 06GM 0043)
2. Lawrence Musaba, Coordination Centre Manager, Southern African Power Pool, Harare, Zimbabwe; Pat Naidoo, Senior General Manager of Transmission Company, ESKOM, South Africa; and Alison Chikova, System Studies Supervisor, Southern African Power Pool, Harare, Zimbabwe. The Southern Africa Power Pool Plan Development. (paper 06GM1330)
3. Abedalgany Athamney, Research Associate, and Wei-Jen Lee, Director, Energy Systems Research Center, The University of Texas at Arlington. Benefits of Facts Devices for Power Exchange among Jordanian Interconnection with other Countries (paper 06GM0352)
4. Frederick T. Sparrow and Brian H. Bowen. The Impact of West Africa's Natural Gas Prices on Energy Trade and Capacity Expansion (Invited Discussion—Tentative)
5. Bai K. Blyden, Engineering Consultant, BRM Group LLC, Elk Grove, USA and Wei-Jen Lee, Director, Energy Systems Research Center, University of Texas at Arlington, USA. Modified Microgrid Concept for Rural Electrification in Africa (paper 06GM1159)
6. Neville S. Arachchige Don, President/CEO, International Research Foundation for Development, Inc**.,** Cambridge, USA. Energy Crisis and Development Issues in Africa: A Critical Need of Strategic (Diagonal and Convergent) Approach to Integrate Africa into Global Economy (paper 06GM0682)
7. Arezki Merkhouf, Electromagnetic Team Leader, and Sonjoy Upadhyay, GE Energy, Peterborough, Canada. Variable Frequency Transformer—An Overview (paper 06GM1333)
8.. Pat Naidoo, Senior General Manager of Transmission Company, ESKOM, South Africa, D Muftic and R Vajeth, Corporate Transmission Line Design Consultants, Trans Africa Projects, South Africa, I Ijumba, Dean of Engineering, University of Kwa Zulu, Natal, South Africa, P Pillay, Visiting Professor of Machines, University of Cape Town, South Africa and University of Clarkson, Canada and A. F. Zobaa, Assistant Professor, Cairo University, Egypt. Human Resources Developments in HVDC Engineering for Continental Grid Application (Invited Discussion)
9. Pat Naidoo, Senior General Manager of Transmission Company, ESKOM, South Africa; L Musaba, W. Balet, and A Chicova. Southern African Power Pool, Harare, Zimbabwe. Feedback Report on the Short Term Energy Market of the Southern African Power Pool as presented to the 2004 General Meeting (paper 06GM0614)
10. **Pat** Naidoo, Senior General Manager of Transmission Company, ESKOM, Johannesburg, South Africa. **The Western Power Corridor Project – Status and Feedback Report** (paper 06GM0620)
11. Adnan Al-Mohaisen, General Manager, GCC Interconnection Authority, Saudi Arabia and Satish Sud, Vice President, Power Systems Energy Division, SNC-Lavalin Inc., Montreal, Quebec, Canada. Update on the Gulf Cooperation Council (GCC) Electricity Grid System Interconnection (paper 06GM0385)
12. 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 of Transmission, ESKOM, South Africa), and Bai Blyden (Engineering Consultant, BBRM Investments, LLC, USA).

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

PANEL SESSION SUMMARY PAPERS

1. Electric Power Development and Trade, and Power Sector Reform in Africa

A. F. Zobaa, *Senior Member, IEEE*, P. Naidoo, *Senior Member*, *IEEE*

Abstract— Africa, as a continent, possesses adequate energy resources for her development, but their distribution across the continent is highly uneven. Africa has only begun to reap the benefits potentially available from integrated energy development. Full integration of energy systems is a very long-term task. Many factors have helped or hindered energy cooperation and integration: the existence of markets which will permit payback for investors, international development policy, economic social and environmental pressures, geography and demography, safely and security, governance, human and institutional capacity and the establishment of collaborative forums and regional and pan-African standards. If future progress is to be optimized, it is vital that the lessons of past experience in all these and other, as yet unexplored, areas are learnt. This paper presents an overview of the energy power development and trade, and power sector reform in Africa.

Index Terms – Energy, Africa, International Practice

I. INTRODUCTION

Efficient, cleaner energy forms are vital to Africa's development and fight against poverty yet the proportion of people still dependent on inefficient and polluting traditional energy sources is higher than any other continent. The traditional approach of constraining energy planning and development within national borders has exacerbated this problem. It is sub-optimal in several critical respects:

- As the geography of energy supply options in no way corresponds to political boundaries, the cheapest and cleanest energy source for a given area may well lie just across the national border rather than in a distant area of the same country.
- Many national markets are too small to justify the investment needed to develop particular energy supply opportunities. Joining national markets can provide the economy of scale to overcome this.
- As markets mature and competition is introduced, the integration of small neighbouring markets can provide the scale necessary for competition to be effective.
- Cross-border energy supply often also provides greatly enhanced diversification of energy source - a key component of energy security.
- Less tangibly, but importantly, joint energy project development can help build closer ties between countries through closer collaboration and increased inter-dependence.

Africa, as a continent, possesses adequate energy resources for her development, but their distribution across the continent is highly uneven. While renewable energy is quite widely disseminated in Africa, this is not true for the mainstay conventional resources. Oil and gas are concentrated in north and West Africa, hydroelectric potential in central and east Africa and coal in southern Africa. It is this pattern of distribution and of energy use that underlies the case for regional, and ultimately continent-wide, integration of energy development.

North Africa's oil, gas and electric grids are largely interconnected with onward links to Europe. The southern African Power Pool links countries from South Africa to the Congo DR and from Mozambique to Angola. East African countries have long shared hydroelectric capacity. Bilateral interconnections in West Africa are planned to come together into the West African Power Pool, supported by the West African Gas Pipeline.

There is no region in Africa where some progress has not been made. Equally, however, it is clear that Africa has only begun to reap the benefits potentially available from integrated energy development. Full integration of energy systems is a very long-term task.

Many factors have helped or hindered energy cooperation and integration: the existence of markets which will permit payback for investors, international development policy, economic social and environmental pressures, geography and demography, safely and security, governance, human and institutional capacity and the establishment of collaborative forums and regional and pan-African standards. If future progress is to be optimized, it is vital that the lessons of past experience in all these and other, as yet unexplored, areas are learnt.

This paper presents an overview of power sector development in Africa [1]-[9].

II. STATUS OF THE AFRICAN POWER SECTOR

Africa has a very small power sector in comparison with its geographic size and population. The size of the power sector, recorded in 2003, is shown in Table I.

TABLE I
POWER SECTOR IN AFRICA

		%	GWH PRODUCTION %	%
West Africa	9498	10,01	21190	6,26
Southern Africa	50007	52,70	197481	58,34
North Africa	28905	30,46	101688	30,04
East Africa	2875	3,03	10083	2,98
Central Africa	3454	3,64	7696	2,27
Totals	94898	100	338485	100

In comparison, the total African power sector is about the same size as the German system, or about a ¼ larger than the size of the United Kingdom system.

III. ENERGY COOPERATION IN AFRICA

North Africa
(Algeria, Egypt, Libya, Morocco, Tunisia)

The electricity grids of the Maghreb Arab Countries are interconnected as follows: Egypt-Libya-Tunisia-Algeria-Morocco (ELTAM).

A Libya-Egypt 220 kV connection came into operation in 1998. The Libya-Tunisia 220kV link was completed in 2001. The Tunisia-Algeria-Morocco 220 kV link has been in synchronous operation with the European UCTE system since October 1997 through a Morocco-Spain 400 kV submarine cable.

The 220kV links from Egypt to Morocco will be upgraded to 500kV/400kV to increase transfer capabilities by 2007.

The electricity grid of the Mashreq Arab Countries is interconnected as follows: Egypt-Iraq-Jordan- Lebanon-Syria-Turkey (EIJLST).

As of 1999 Egypt and Jordan are connected via a 500kV/400kV overhead and submarine cable from Suez, in Egypt, to Aqaba in Jordan. Jordan, Syria and Turkey are interconnected via 400 kV lines. The Jordan-Syria interconnection came into operation at the beginning of 2001 and Syria-Turkey at the beginning of 2002. Lebanon will be connected to the Syrian grid in 2003 via a 400kV link.

The Turkish power system is electrically connected to the UCTE system via two 400KV lines through Bulgaria. An additional 400kV connection is planned between Turkey and Greece. In the future, Turkey plans to be in synchronous operation with the UCTE system via either of its connections with Bulgaria and Greece.

This would mean that the East and Southern Mediterranean countries, stretching from Turkey to Morocco would be in connection with the European UCTE system via the existing Spain-Morocco link or the connections with Greece or Bulgaria. These links will form the basis for a Mediterranean Power Pool (MPP) and enhance regional power trade in North Africa and the Mediterranean Basin.

At present Mauritania, a Maghreb country in the West Africa region, has energy ties with Mali. In line with AMU undertakings, an interconnection between Morocco and Mauritania is under investigation. Political considerations may influence this interconnection.

West Africa
(Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo)

The WAPP is dependant on two major primary energy sources:

- Gas for thermal power stations - see next section on WAGP
- Hydropower, mainly on the Niger (Nigeria), Volta (Ghana), Bafing (Mali), and Bandama (Côte D'Ivoire) Rivers.

There are plans in Ghana to build an additional station (400MW) on the Black Volta River that could possibly export power to Burkina Faso, Côte d'Ivoire and Mali. This is in addition to the gas-powered stations previously mentioned. Ghana is also supplying power to the power grids in Benin and Togo from the Akosombo Plant on the Volta River.

Nigeria's National Electric Power Authority (NEPA) is planning a 330kV line from Lagos to Benin as part of a larger West African interconnection involving Niger, Benin and Togo, whilst Ghana has a planned interconnection with Ouagadougou in Burkina Faso. There is an existing interconnection between Burkina Faso and Côte d'Ivoire. The latter and Ghana are already interconnected, and an interconnection is planned with Mali which could supply as far as Bamako in Mali.

A second phase of this project will include Guinea, Sierra Leone and Mali.

The Manantali Project on the Bafing River in the west of Mali came on line in July 2002 and, supplemented by supplies from Côte d'Ivoire, will ensure a dependable local supply as well as links to Senegal and Mauritania.

The combination of existing and planned projects will provide a sound basis for eventual electrical cooperation in most of West Africa, excluding just Liberia and Sierra Leone.

Recently released information from ECOWAS lists the donors who will finance the WAPP project. A consortium consisting of Agence Française de Developpement, the World Bank, the European Investment Bank, the West African Development Bank and the Nordic Fund will contribute. The two most costly interconnections are those linking Bobo Diolasso to Ouagadougou in Burkina Faso and Ferkessedou in Côte d'Ivoire to Segou in Mali, at an estimated 85 million Euros each.

North and West Africa (inter-regional)

In 2002 the Presidents Olusegun Obasanjo of Nigeria and Abdelaziz Bouteflika of Algeria agreed, in principle, to the concept of a Trans-Saharan Gas Pipeline, NIGAL, which had been suggested by the Nigerian Presidential Advisor on Petroleum and Energy, Dr. Rilwanu Lukman, and Algerian Energy Minister, Chakib Khelil. The pipeline would link the major Nigerian gas fields to the gas fields of Algeria with their interconnecting pipelines to other countries. Although this project is in an early stage of investigation and many details have yet to be worked out, it would provide Nigeria with access to European markets, via Morocco and Spain or via Tunisia and Italy.

The 4000km pipeline would be routed via Niger and would cost in the region of US$ 5 billion. The project would thus link three countries and two regions. The possibility of linking to yet another region - central Africa - through a pipeline linking Cameroon to Nigeria has been discussed, though border tensions between these two countries are likely to delay serious study of it. Should it happen, it would open a market for the enormous amounts of gas that at present are being flared on the west coast of Africa from Cabinda in Angola to Cameroon. Nigeria will continue producing enormous volumes of gas, with or without the pipeline. As a result of the government's promise to end gas flaring by 2008, markets will be needed to absorb the associated gas that is currently wasted. West Africa will probably not generate enough demand to consume all Nigerian gas production in the short to medium term. Nigerian gas must be exported further field, either in the form of LNG or piped gas.

Secondly, the Nigerian government is keen to boost its income and if the country remains an OPEC member, its oil production levels may remain restricted. There is no such restriction on the production and export of natural gas. Finally, demand for gas within the EU is likely to rise substantially over the next decade as, mainly on environmental grounds, the European Commission favours gas over oil or coal fired power generation. There could also be a similar shift in Eastern Europe as EU applicant countries struggle to meet EU environmental and energy standards.

East Africa
(Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, Uganda)

As in West Africa, drought has had dire consequences for east African electricity supplies. In the late 1990s this resulted in power rationing in Kenya and Tanzania. In 2001 Kenya, Tanzania and Zambia decided to facilitate cross border energy trade. In addition Uganda exported power to Kenya from Kiyara Power Station.

In the next decade Uganda plans to upgrade its capacity by an additional 5 units at Bujagali (200MW) and Karume. Nalubaale (formerly Owen Falls) is to be upgraded and extended. There is serious environmental opposition to the Bujagali scheme, however, which is situated in a scenically beautiful area some miles downstream from Nalubaale. However as of July 2003 AES, the principal US utility involved in the project, has officially pulled out. The Ugandan government is currently seeking new partners.

A Kenya-Tanzania study is being undertaken, the objective of which is to examine the technical and economic viability of a transmission line between Nairobi and Arusha in order to facilitate the exchange of power between the two countries and eventually with the South African Power Pool (SAPP) when Tanzania is interconnected to Zambia. The study has identified a possible line route, optimum transmission voltage and environmental impacts including possible mitigation measures to be taken.

The study is being financed jointly by the governments of Kenya and Tanzania and has been carried out by BKK of South Africa and Acres International of Canada. The proposed 330kV line is approximately 260km long. The study, which commenced in October 2001, has been completed and the consultant presented the draft report in Arusha in June 2002. The final report, incorporating comments from Kenya and Tanzania, was issued in late 2002. It is hoped that private investors may be interested in the implementation of this project.

Uganda has recently signed a management contract with South Africa's Eskom Enterprises to manage its power stations for a period of 20 years. A similar contract covering transmission is still to be negotiated, but there is only a single tendered.

The governments of Tanzania and Zambia are jointly funding a study to look at the technical and economic viability of a transmission line between the two countries. The proposed study would review earlier studies that had identified a 700km 330kV line. The study would also look at the reinforcement required on Tanzania's 220kV system to enable transfer of power from the South African Power Pool to Kenya.

Consultancy proposals for the study are currently under evaluation after an international bidding process through which 6 firms were short-listed. The study is scheduled for completion in 2003.

North and East Africa (inter-regional)

A scoping study was carried out in 1999 to look at opportunities for power trade in the Nile Basin. Several options for increased trade were identified and further studies are proposed to select the most economically viable projects for regional power generation and interconnection. The proposed Nile Basin Initiative Forum will create and support a regional power market:

- By facilitating the creation of institutional and physical infrastructure for power trade;
- By assisting in the development of power markets and identifying appropriate projects for implementation.

Ten countries, Egypt, some of which have only peripheral connection with the Nile Basin, are involved in the Nile Basin Initiative (NBI).

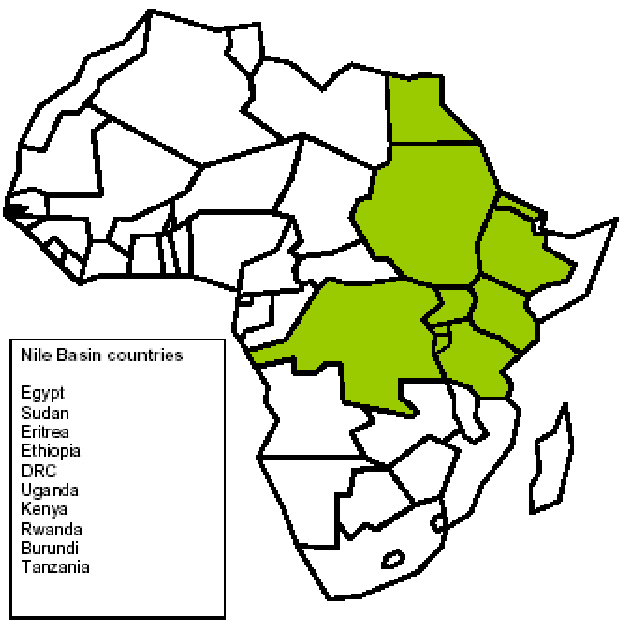


Fig. 1 Countries of the Nile basin initiative

The NBI secretariat, based in Entebbe (Uganda), coordinates several activities. The key objective of the NBI is to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the common Nile Basin Water Resources. The NBI will create processes to promote power trade and advance the development of power supply facilities. Ultimately a fully-fledged Power Pool is envisaged for the Nile Basin.

Central Africa
(Cameroon, Central African Republic, Chad, Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon, Sao Tome & Principe)

The giant of potential central African electricity integration projects is the Inga project on the Congo River. Its implications are so geographically broad, however, that it is covered in the following Interregional section.

Advanced negotiations are taking place between Cameroon and Chad for a power line between Maroua (Cameroon) and Kousseri (a diesel power station in Chad). This is a 225kV line 255km long, with two step-up transformers on the Cameroon side and a step down transformer near Kousseri.

A number of Cameroon's neighbours have expressed interest in acquiring hydropower from it as the country has extensive possibilities in this respect (799MW capacity in 1999).

There is an interconnection between the Democratic Republic of Congo and Congo Brazzaville. Apart from the interconnections already mentioned, most of the countries in the region are isolated, with no links to other countries.

Central Africa and the Inga Project (inter-regional)

Of the enormous hydropower potential of the Congo River, the lion's share, some 44GW, is at Inga, a series of rapids about 150km from the mouth of the river. In a continent plagued by droughts the site is virtually drought proof as the Congo's tributaries drain a vast area spanning both sides of the Equator. The flow is a steady 42 000 cubic meters per second.

The rapids at Inga make it one of the most significant hydro sites in the world. Coupled to the fact that the site can deliver cheap energy, because of the specific topography it can do so at minimal environmental impact. Its low production costs make it a very interesting proposition.

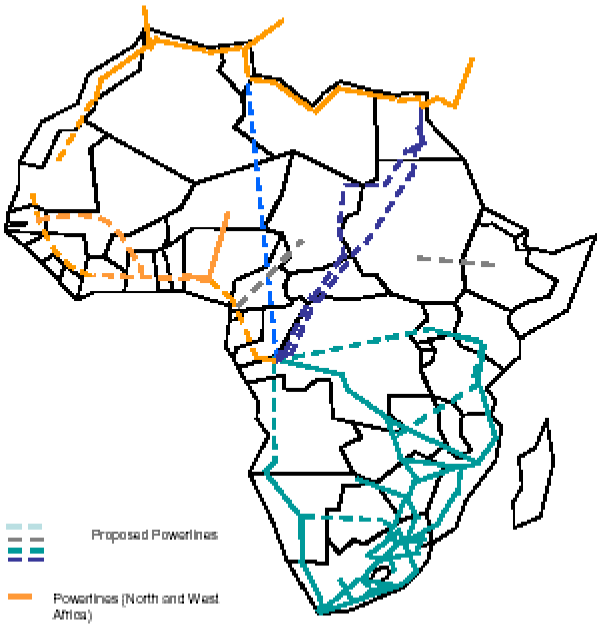
The significance of harnessing this potential has long been recognized. Not only could the Inga project be the giant of central African electricity integration projects, it is arguably the most ambitious integration project ever contemplated in Africa. Its potential capacity is such that its implications reach from the north to the south of the continent and it would constitute the hub of the visionary pan-African electricity grid, Fig. 2.

The first 3 phases of the Inga development are situated here:

- Inga 1 - 351MW - commissioned in 1972
- Inga 2 - 1424MW - commissioned in 1982
- Inga 3 - 1700 to 3500MW - projected

Grand Inga involves the damming of the river to divert the flow to the neighbouring Biridi Valley, thereby using the rivers full flow. In the final stages 52 generators of 750MW each would generate 39 000MW. A feasibility study has been undertaken and start-up is planned for 2008.

Fig. 2. Present and potential African grid



The development of Grand Inga will require the construction of an extensive transmission network to supply power to other countries, as the supply will far outstrip the requirements of the DRC. Three main 'axes' are contemplated:

- The DRC - Southern Africa axis (see map under SAPP),
- DRC - Central Africa/ Western Africa axis,
- DRC - North Africa axis.

When the Inga scheme on the Congo River finally comes into operation the network created by the Nile Basin Initiative would have considerable strategic significance, as it would offer a corridor for export of Inga electricity to the established markets of Europe. Revenues from such exports would allow payback of the investment and facilitate investment in other power projects in Africa. In this sense the Nile Basin Initiative may be seen as paving the road for Inga.

Southern Africa
(Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe)

The Southern African Power Pool (SAPP) was established in 1995 with the primary aim of providing a reliable and economically viable electricity supply to the consumers of each of the SAPP members, consistent with the reasonable utilization of natural resources and the minimization of environmental impact.

According to the United Nations Economic Commission for Africa's "Assessment of power pooling arrangements in Africa 'The SAPP agreement states the purpose of the Pool as being to allow its members to coordinate the planning and operation of their systems, while maintaining reliability, autonomy and self-sufficiency and sharing in the benefits of operating the pool, including reduction in required generating capacity and reserves, reduction in fuel costs and improved use of hydro-electric energy'.

This is the most advanced of the integration schemes on the African continent in terms of practical realization and stretches beyond the Southern African Development Community to include Tanzania and the DRC.

IV. WEST AFRICAN GAS PIPELINE (WAGP) PROJECT

In 1982, The Economic Community of West African States (ECOWAS) as one of its key regional economic policies, proposed the development of a natural gas pipeline throughout West Africa. ECOWAS's regional energy distribution plan (1991) and a feasibility study on the supplying of Nigerian gas to Ghanaian markets (1992) further enhanced the practicality and need of developing a regional pipeline. A feasibility report, prepared for the World Bank in the early 1990's, deemed that a pipeline to transport Nigerian natural gas to Benin, Togo and Ghana was commercially viable. The report's conclusion was based on the U.S.-firm Chevron's associated gas reserves in Nigeria's Escravos region. In September 1995, the governments of the four nations signed a Heads of Agreement (HOA) pertaining to the pipeline project. The HOA broadly outlined the principles of the pipeline development.

An energy shortage experienced by Ghana, Togo, and Benin in 1997-1998 renewed interest in the pipeline project. In August 1998, a consortium of Chevron, Shell, Nigerian National Petroleum Corporation (NNPC), Ghana National Petroleum Corp. (GNPC), Societe Beninoise de Gaz (SoBeGaz), and Societe Togolaise de Gaz (SoToGaz) signed an agreement commissioning a feasibility study on the West Africa Gas Pipeline (WAGP), Fig. 3.

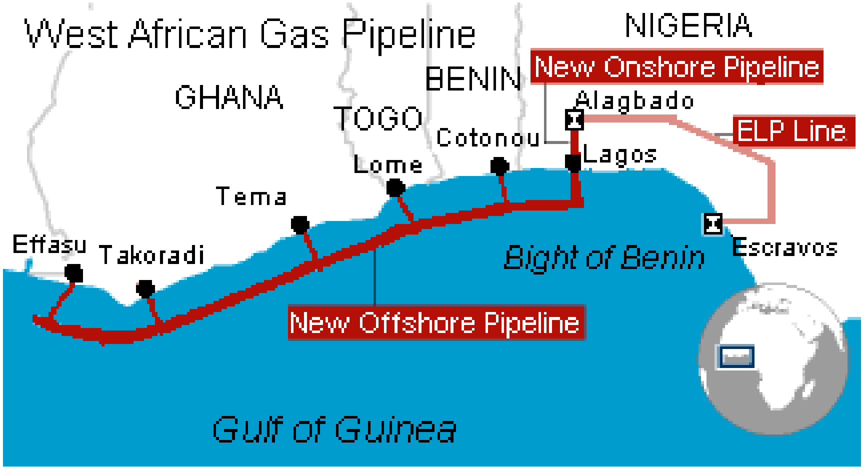


Fig. 3. WAGP project

The study, which was completed in March 1999, concluded the commercial and technical viability of the WAGP, and projected that it could be operational as early as 2002. On August 11, 1999, in Cotonou, Benin, a Memorandum of Understanding was signed by the four countries and the consortium establishing the legal framework for the WAGP. The Joint Venture Agreement naming Chevron as the WAGP project manager was signed on August 16, 1999 in Abuja, Nigeria. In February 2000, the four nations signed an Inter-Governmental Agreement (IGA), which established the framework for realizing the pipeline venture. The IGA includes the government's commitments to the pipeline owners and gas distributors on the conditions for the development, construction and operation of the WAGP, as well as fiscal and customs policies for the venture. The project has received administrative support from the ECOWAS Secretariat and technical assistance ($1.55 million) from the United States Agency for International Development (USAID).

In June 2002, a gas supply agreement for Ghana's Takoradi power plant was signed. The gas is expected to significantly reduce boiler-fuel costs at Takoradi by substituting gas for oil. In February 2003, the four nations signed an agreement on the implementation of the WAGP. The treaty, which is for a 20-year period, provides for a comprehensive legal, fiscal and regulatory framework, as well as a single authority for the implementation of the project. The WAGP partners are Chevron Texaco with 36.7%, NNPC with 25%, Shell with 18%, Ghana's Volta River Authority (VRA) with 16.3% and SoBeGaz and SoToGaz each with a 2% interest.

V. PROMOTION OF REGIONAL AND SUB–REGIONAL ELECTRICITY CO-OPERATION

There is a need for mutually beneficial regional electricity trade, where all participants can be perceived as 'economic gainers'. To meet the rapidly growing demand, and to improve the continent's prospects for sustained economic growth and development, a commitment from all countries is urgently needed to bring about regionally integrated solutions and significant new investment in energy infrastructure, particularly for interconnections.

SAPP is a working example of the benefits that can be obtained from regional cooperation in electricity trade. It is a successful African case study, which can be replicated into other regions.

All countries in the various regions of Africa can benefit from promoting regional solutions to regional energy problems. This can result in –

- Increased bilateral and multilateral cross border trading in energy resources;
- Increased availability of clean energy for regional consumption;
- New infrastructure built for cross-border transmission and transport of electricity;
- The development of regional energy markets that rationalize the development, transit and use of energy sources across the region and thus reduce the region's total energy costs and increase its energy security;
- Sufficient flexibility for the region's utilities to work together with private investors to implement the most economically viable projects to meet the region's increasing energy demand in an economically efficient and environment sustainable manner;
- The extension of reliable, good quality and paid for electricity to all populations;
- Attracting energy dependent industries into Africa; and
- The steadily improving quality of life for the region's increasing population.

Building on the successes already evident in Africa, increasing cross-border trade in electricity can act as the engine for economic growth and development of the continent for the benefit of her people.

VI. ACTION PLANS

It is important to recognize that agreed-to plans must be capable of being realized. It is not ideal to put forward a suite of proposals that are unlikely, for a variety of reasons, to be achievable.

It is accordingly proposed that the following broad approach be followed:

- Focus be placed on the improvement of the performance of the power sector in each country;
- Promotion of / increase in cross-border trading to be identified and implemented;
- Regional plans be identified for the trading of electricity on a regional basis (such as SAPP and WAPP);
- Inter regional trading opportunities be identified for implementation at an appropriate time.

The following action plans are therefore proposed-

- The conclusion of an 'Energy Treaty' (along the lines of the Energy Charter Treaty of the European Community) to be concluded at NEPAD or African Union level. The treaty will encourage co-operation in energy matters. It will essentially say that all countries will consider regional options when making decisions about their local energy needs/future needs;
- Establishment of an 'African Forum of Power Utilities' as a place where power utilities can foster cooperation;
- Acceleration of the activities of the African Forum for Utility Regulators as the forum for co-operation between African regulators (with the power sector being given special attention);
- Establishment of a Committee of African Energy Officials under the NEPAD initiative to facilitative the harmonization of a common and consistent legal and regulatory framework to promote cooperation in the power sector, as well as the harmonization of standards and specifications;
- Acceleration of the already identified NEPAD power initiatives to demonstrate that benefits can be realized under cross-border energy trading.

The idea is to learn from the initiatives already underway (such as SAPP and WAPP), while continuing with bi-lateral and regional co-operation under the

'Political umbrella' of an Energy Treaty, which will foster ongoing regional cooperation.

As part of the process of moving forward, countries will have to accept certain objectives and principles which will guide them towards accelerating regional and inter-regional electricity trade. These can be included in the Energy Charter.

VII. CONCLUSIONS

Electricity trade between African countries can be increased considerably. This will reduce total energy costs and increase energy security. Working together will boost trade and bring benefits to the economies of participating countries, and promote the socio-economic well being of their populations. But it is necessary to remove existing barriers to trade to achieve this, and action must be taken to introduce the reforms that are needed to attract investment.

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IX. BIOGRAPHIES

Ahmed Faheem Zobaa (M'01-SM'04} received the B.Sc.(hons.), M.Sc. and Ph.D. degrees in Electrical Power & Machines from the Faculty of Engineering at Cairo University, Giza, Egypt, in 1992, 1997 and 2002.

Currently, he is an Assistant Professor in the Department of Electrical Power & Machines, at Faculty of Engineering, Cairo University. He was an Instructor in the Department of Electrical Power & Machines, with the Faculty of Engineering at Cairo University from 1992 to 1997 and Teaching Assistant from 1997 to 2002. His areas of research include harmonics, compensation of reactive power, power quality, photovoltaics, wind energy, education and distance learning. He is an Editorial Board member for *Electric Power Components & Systems Journal*, *International Journal of Emerging Electric Power Systems*, and *International Journal of Computational Intelligence*. He is an Editor for *IEEE Power Engineering Letters* and *IEEE Transactions on Energy Conversion*. Also, he is an Associate Editor for *IEEE Transactions on Industrial Electronics*, *Electrical Power Quality and Utilization Journal*, *International Journal of Power and Energy Systems*, *International Journal on Modelling and Simulation*, *International Journal of Energy Technology and Policy*, and *Neurocomputing Journal*.

Dr. Zobaa is a member of the IEEE Power Engineering / Industry Applications / Industrial Electronics / Power Electronics Societies, Institution of Electrical Engineers, the International Association of Science and Technology for Development and the International Solar Energy Society.

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.

2. The Southern African Power Pool Plan Development

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Abstract - The Southern African Development Community (SADC) region is endured with a lot of power generation potential. Integrated generation and transmission expansion is the objective of most power pools. This leads to economic and efficient use of energy resources. Utilities should benefit from the diversity of energy resources in terms of the use of different technology for power generation be it hydro, gas, coal or renewable energy.

Keywords**:** Pool Plan, Integrated Plan

I. INTRODUCTION

Demand in the Southern African Power Pool (SAPP) is increasing at a rate of about three percent per annum. The reasons for the increase in power demand has been attributed to [1] (i) increase in the population of most SADC member states, (ii) economic expansion in member states requiring more power to supply the new industries, and (iii) non-economic tariffs in most of the member states that do not support re-investment in power generation, but allow for large energy intensive users to come into the SADC region and set up their operations.

If no new power generation stations are built in the region, then it is predicted that the region would run out of excess generation capacity by the year 2007. It is a target for the SAPP member utilities to commission rehabilitation, short term and long-term generation projects to avoid this deficit.

II. DEMAND PROJECTIONS

The total available capacity in the SAPP is about 45,000MW while the total demand is moving closer to 42,000 MW. Each year approximately 1,200 MW of new generation capacity should be commissioned to meet the ever-increasing load demand. Figure-1 shows the current demand-supply situation.

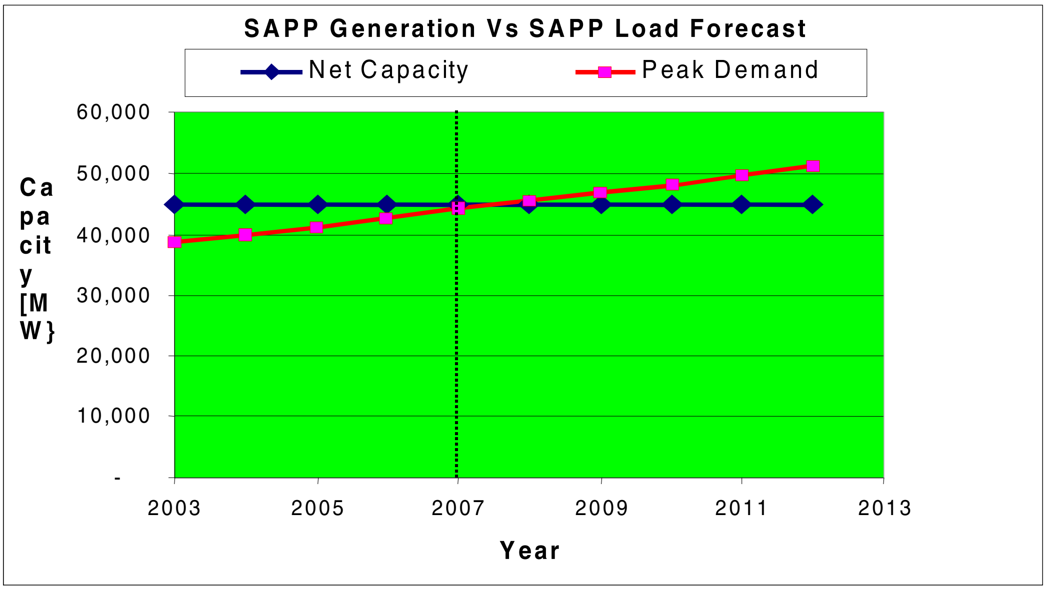

Figure-1. SAPP Peak Demand Projections

III. GENERATION MIX

There are abundant coal resources in Southern Africa and this constitutes over 75% of the current total generation with the majority being in South Africa. Hydro resources are the second and they constitute 20 % with nuclear and gas constituting 4% and 1.6 % respectively, as illustrated in Figure-2. In terms of country generation, South Africa accounts for more than 80% of the total regional generation, Figure-3.

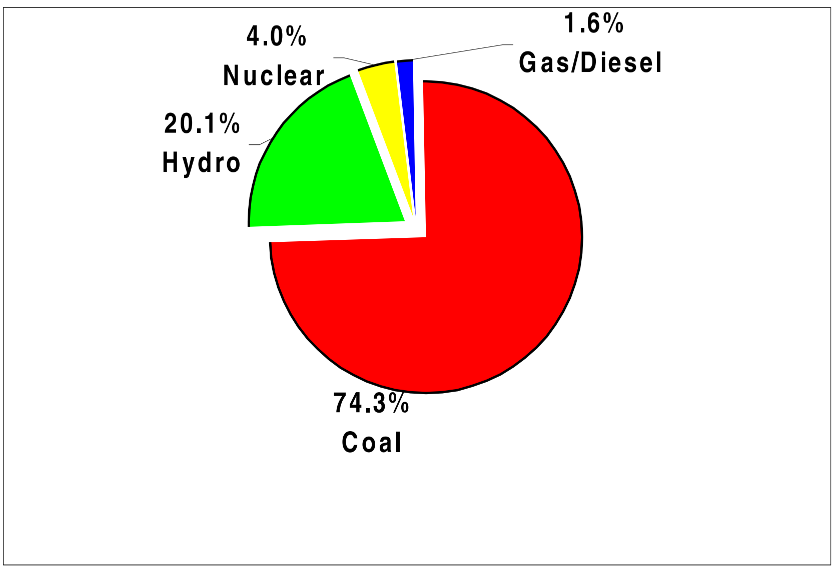

Figure-2. Generation Mix by Technology

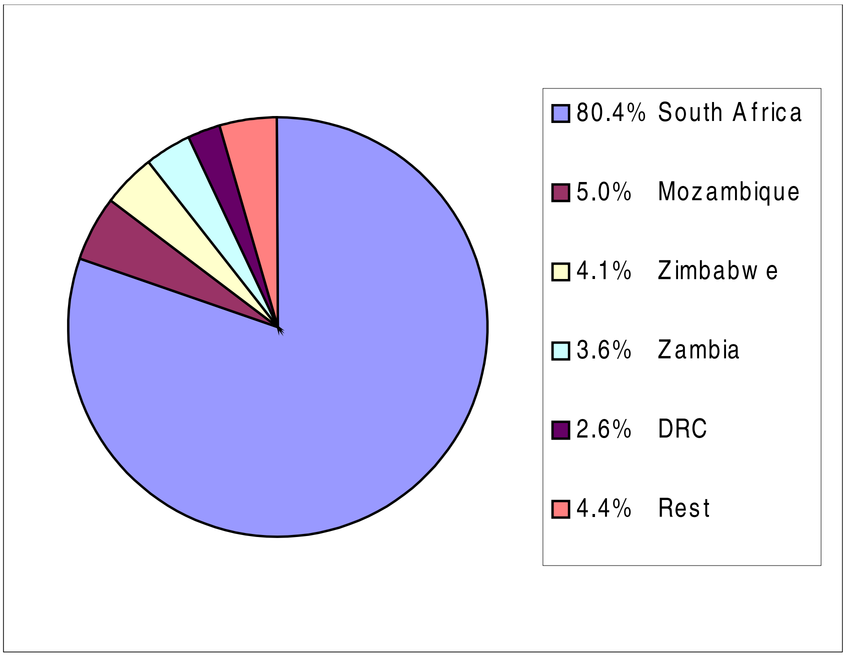

Figure-3. Generation Mix Country

IV. POOL PLAN DEVELOPMENT

In 2001, the SAPP developed an integrated least cost generation and transmission plan [2]. The plan was financed by USAID. It was concluded that if individual utilities developed their own expansion plans with their own criterion, it would cost the region approximately USD11 billion over a period of 20 years. An optimal regional expansion plan would cost USD8 billion, which would be USD3 billion cheaper. This demonstrated the economic benefits of integrated planning and the pooling of resources. The Pool Plan results did not entail members to strictly stick and develop the identified generation and transmission projects. The selected plan was subjected to qualitative risk and uncertainty analysis, which included the following:

- Load forecast
- Energy availability (drought)
- Resource costs
- Discount rate (interest rate)
- Generating plant availability

- Interconnection availability
- Generation options
- Impact of restructuring

The selected best-case overall plan included the promotion of the following projects:

i. Inga 1 & 2 in the DRC, to be refurbished from 2003 onwards.
ii. High Head Pump storage in North-South Africa, to be commissioned in 2005-2008.
iii. Kafue Lower in Zambia, to be commissioned from 2007 to 2012.
iv. Mepanda Uncua in North Mozambique, to be commissioned from 2011 to 2016.
v. Inga 3 or Grand Inga stage 1 in the DRC, to be commissioned from 2013 to 2020

The economic conditions, load growth, demographic and planning assumptions, under which the Pool Plan Projects were selected have since changed, and hence the SAPP is revising the Pool Plan to meet the current challenges.

In the interim and before the SAPP Pool Plan is revised, the SAPP agreed that the priority projects for the region were as follows:

i. All rehabilitation or refurbishment projects together with the associated transmission infrastructure projects. The transmission projects so considered in this case were aimed at relieving congestion and evacuation of power to the load centres.

ii. Short-term generation projects with the following features:

- Expected to be commissioned on or before 2010,
- Completed feasibility studies, and
- Approved environmental impact assessments.

iii. All transmission projects that were aimed at interconnecting non-operating members of the SAPP to the grid and these were identified as:

- Malawi-Mozambique interconnector,
- Zambia-Tanzania-Kenya interconnector, and
- Westcor project. This project aims to interconnect Inga-3 in the DRC to South Africa via Angola, Namibia and Botswana.

V. CONCLUSION

The development of a single integrated expansion plan for the SAPP has great benefits to the Southern Africa region as it will lower the cost of generation and transmission expansions and will enhance the effective use o regional resources. Over investment in the region would also be avoided. With scarce resources in Africa, a integrated plan is the best option.

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VII. ABOUT THE AUTHORS

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3. Benefits of FACTS Devices for Power Exchange among Jordanian Interconnection with Other Countries

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Abstract: Transmission system is the backbone of the electrical power delivery system. It is essential to maintain safety and efficient operations of the transmission system on both steady state and transient using different methods to improve the overall performance of the power system. In addition to construct new transmission lines, Flexible AC Transmission System (FACTS) are effective devices to increase the transfer capacity, improve different stability aspects, and control the power flow especially for the interconnected systems.

The Mediterranean Ring, a major international electric power interconnection project initially conceived of during the 1960s. It plans to connect electric power transmission grids among the countries that encircle the Mediterranean Sea. Hashemite Kingdom of Jordan reigns over a strategic location among the middle-east countries. It is bordered with Iraq, Syria, Saudi Arabia, Israel, and the Palestinian Authority Territory. Power transfer capabilities between Jordan and its neighboring countries play important role in the effectiveness of the Mediterranean Ring.

This paper studies the impact of FACTS on the performance of Jordanian transmission system under different levels of power exchange with Egyptian and Syrian power systems. This will help to determine the appropriate types and locations for FACTS devices to be installed to improve these limits.

Keywords: Pan-Africa interconnection, Mediterranean Ring, FACTS, Voltage stability, Power exchange**.**

I. INTRODUCTION

The continent of Africa has 15% of the world land area and extends from about the 35° north of the equator to about the 35° south of the equator. According to the report in [1], the total installed capacity of Africa is 94,898 MW in 2003. The New Partnership for Africa's Development (NEPAD) was developed in 2001 to merge the various initiatives then being developed by different African leaders. It was presented to the G8 Heads of State in June 2002 and launched at the World Summit on Sustainable Development in Johannesburg in August-September 2002. It is believed that regional cooperation and integration through energy pooling and cross-border energy trading would help economic development of the continent. In the electricity sector, the concept of Pan-Africa Interconnection formed and the backbone transmission grid is shown in Fig. 1. The main developing includes Northern Africa (Mediterranean Ring Project), Western and Southern Africa.

The Mediterranean Ring, a major international electric power interconnection project initially conceived of during the 1960s. It plans to connect electric power transmission grids among the countries that encircle the Mediterranean Sea. The concept involves linking electric power grids from Spain to Morocco through the remaining Maghreb (North African and Western Arab) countries, on to Egypt and the Mashreq, (Eastern Arab) countries, and from there up to Turkey. From Turkey the ring would then link back into the European grid via Greece or through the newly interconnected Eastern European country grids. The purposes of this project are 1) enhancing levels of system security to participating countries, 2) deferring or avoiding construction of new power plants by sharing electric power among nations, and 3) reduce the electricity reserve requirements within each country.

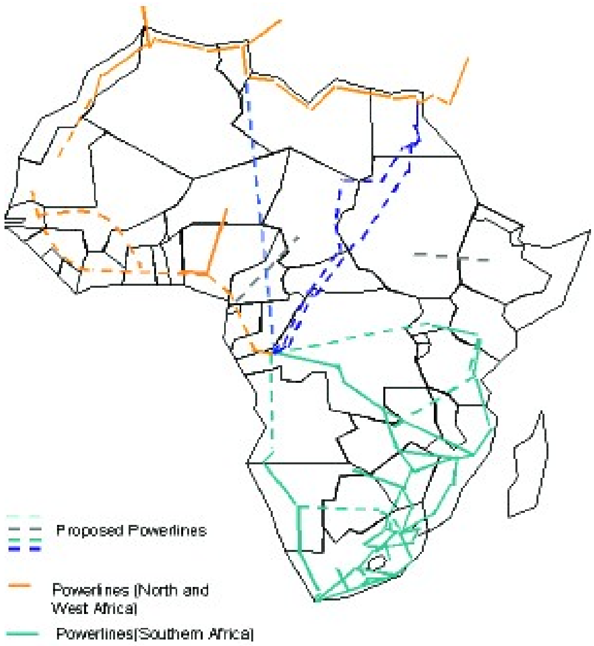

Fig. 1. Pan-Africa Interconnection

As shown in Fig. 2, Hashemite Kingdom of Jordan reigns over a strategic location among the middle-east countries. It locates on the northern side of the red sea at Aqaba gulf, with population of approximately 5.6 million. It has a territory of 89,566 square km (34,578 sq.mi) and is bordered with Iraq, Syria, Saudi Arabia, Israel, and the Palestinian Authority Territory.

In addition to Egypt, Iraq, Lebanon, Libya, Syria, and Turkey, Jordan is one of the countries who are involved in the seven countries interconnection project (EIJLLST). Two interconnection projects are already accomplished with Egypt and Syria, Due to the unstable situations in the region, a presumed project with Iraq was put onhold.

Due to the shortage of investments, the possibilities to construct new generation units in the developing countries are limited. Strengthen tie lines that interconnect different grids to share the generation resources among regions or countries become an attractive option. A 20 km (12.43 mile) in length with maximum 850 meter (0.528 mile) in depth submarine cable connects the 500/400KV substation at Taba in the Egyptian side and 400KV GIS substation at Aqaba in the Jordan side with 600MW exchange capacity. The transfer level can be doubled by transferring DC power instead of AC. The power systems of Jordan and Syria are tied together through a 400KV overhead transmission line (single circuit), which enables the two countries to receive the benefits of this interconnection by smoothing their demand profiles and reducing the reserved generation capacity. The installed capacity and peak demand of Jordan, Egypt, and Syria are shown in Table 1.

Table 1. The installed capacity and maximum demand

Country	Installed Capacity(MW)	Peak Load(MW)
Jordan	1650	1500
Syria	7000	4500
Egypt	17500	14000

Though using power pool to supply the load centers can reduce the overall installation capacity, some problems, such as power flow control, dynamic stability, voltage stability, and transient stability may occur. In addition, the risk of the blackout is increased in case of cascaded interruption. The advance in the power electronics technologies makes it possible to improve the power system performance by applying the "Flexible AC Transmission Systems" (FACTS) devices in the transmission system. Every FACTS controller has a specific advantage over the other types, which justifies the deployment of certain types of controller for specific applications. Depends upon the type of FACTS devices, it has the capability to increase the line capacity, enhance the system stability, regulate the voltage profile, mitigate system oscillations, control power flow, or share load among parallel corridors.

This paper studies the impact of FACTS on the performance of Jordanian transmission system under different levels of power exchange with Egyptian and Syrian power systems.

Fig. 2. Map for the geographic location of Jordan

II. JORDANIAN POWER SYSTEM

As shown in Table 2, the power demand in Jordan has grown rapidly and is expected to continue increasing in the future. The performance of the Jordanian power system sector can be considered as an efficient system when comparing with those countries with the same state of economic development.

Table 2. Electricity demand forecast in Jordan

Year	Max. Demand		Electrical Energy	
	MW	Growth %	GW.h	Growth %
1999	1099	7.7	7081	5
2000	1206	9.7	7375	4.2
2001	1255	1.4	7544	2.3
2002	1410	12.4	8449	8.2
2003	1453	3.0	8812	4.3
2004	1553	6.9	9404	6.7
2005	1698	6.8	9978	6.1
2006	1762	6.3	10657	6.8
2010	2021	2.6	12432	2.8
2015	2262	2.3	13909	2.3

A. Generation System

The Central Electricity Generation Co. (CEGCO) is responsible for the power generation in Jordan. The majority of Jordan's power generation is supplied by two main power plants, Aqaba Thermal Power Plant (5 units × 130 MW) in the south of Jordan at the Aqaba gulf, and Hussien Thermal Power Plant at Zarqa (4×66MW + 3×33MW) located in the middle of the country.

Table 3. Annual Electrical Energy Production (GW.h)

Steam	Natural Gas	Diesel	Others
7205	680	71	171
88.7 %	3.5 %	0.87 %	2.1 5

B. Transmission System

The National Electric Power Company (NEPCO) owns the high voltage network to transmit the electrical power from the generation plants to the distribution networks.

The voltage levels for transmission lines are 66, 132, 230, and 400 KV, which connect the main substations dispersed across the country to provide the electrical energy to the load centers at different distribution voltage levels. In addition to the management, operation, and development of the high voltage national grid in the country, NEPCO is also responsible for the interconnections with neighboring countries.

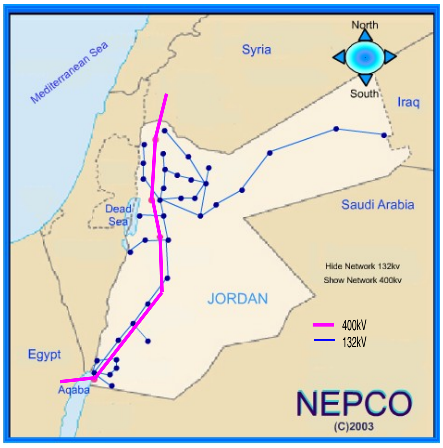

Fig. 3. 400KV and 132 KV National Transport Network

Table 4. H.V Transmission Lines length (km, mile)

Voltage Level	400KV	230KV	132KV	66KV
Length in km	809	17	2211	17
Length in mile	502.7	10.6	1373.9	10.6

C. Distribution System

The voltage levels for the distribution network in Jordan are 33, 11, 6.6, 3.3 and 0.4 KV. The distribution network in Jordan's power system is operated by the following three companies:

- Jordan Electric power Company (JEPCO) covers the middle part of the country.
- Irbid Distribution Electricity Company (IDECO) covers the northern area.
- Electricity Distribution Company (EDCO) covers the southern and eastern areas of the kingdom.

Conjuncture of Jordan's Transmission System

More than 40 percent of the installed generation facilities in Jordan are located in the southern part at Aqaba Thermal Power Plant (656 MW of 1632 MW) which have to be transported to the load centers located in the northern, middle, and southern areas through the following two transmission paths:

- 400 KV (double circuit towers) radial transmission line: Starts from 400/132/33 Kv Aqaba substation (which is also connected to the east side of the 400 KV Jordan-Egypt interconnection submarine cable) extends north to Quatrana 400/132/33 KV substation toward Amman South 400/132/33 KV substation which is connected to Amman North 400/132/33 KV substation, the interconnection point with Syria.
- 132 KV network: Starts from Aqaba south and passes through many 132/33KV substations in the southern and middle areas until reaching Amman South 400/132/33 KV substation. This 132kv network extends to the northern and also to the eastern substations to reach Resha Power Station at the borderline with Iraq territories.

Jordan’s transmission network requires upgrading in the transfer capacity in certain lines to meet the continuous growth in demand for electrical energy. The other purpose for upgrading the transmission system is to activate the seven country interconnection (EIJLLST) system by increasing the existent exchanged power with Syria, Egypt, and other neighboring countries such as Iraq. To accomplish this purpose, an increase in the transferring capacity of the network between Aqaba and Amman South should be executed.

Increasing the transferring capacity of the network betweens Aqaba and Amman will result in advantageous effects on the stability margin of Jordanian power system, the avoidance of blackout teaser in case of emergency condition, strengthening the infrastructure of (EIJLLST) interconnection between the seven countries which have different peak load hours, and sharing the generation resources. All of these will facilitate the formation of competitive electrical markets in the future.

III. COMPUTER SIMULATION AND PROPOSED APPROACHES

Table 5 shows the voltage profile of 400KV substations and selected 132 KV substations in the base case conditions.

Table 5. The Voltage at Different Substations (Base Case)

Substation		Rated Voltage (KV)	Voltage (p.u)
No.	Name		
309	Aqaba Cable	400	1.04
521	Aqaba ATP	400	1.0391
5200	Qatrana	400	1.064
522	Amman South	400	1.044
544	Amman North	400	1.039
21	Amman South	132	1.055
1	Zarqa	132	1.050
23	Subihi	132	1.0059
229	Ishtafina	132	1.0053
231	Waqas	132	1.0072
63	Sabha	132	1.036
59	Azraq	132	1.038
7	Irbid	132	1.034

A. Examining the Power Exchange limitations

Though the Jordanian power system (Base Case) is normal under the current power exchange levels with Egypt and Syria, it is planned to increase the level of the power exchange in the future. If the exchanged power with the other countries increased through the existing power system without infrastructure improvement, problems in different aspects of stability may appear. To examine the possible negative impact on system stability due to the increase of power exchange, the case of Jordan-Egypt interconnection is simulated using PSS/E to obtain the Power-Volt relationships in major Jordanian buses at different levels of power exchange. The following figures show the impact of exchanged power levels on the bus voltage.

Fig. 4 shows the Power-Voltage curves at base case and contingency case, when a circuit in the 400KV branch between Qatrana's bus (# 5200) and Amman South bus (# 522) is opened.

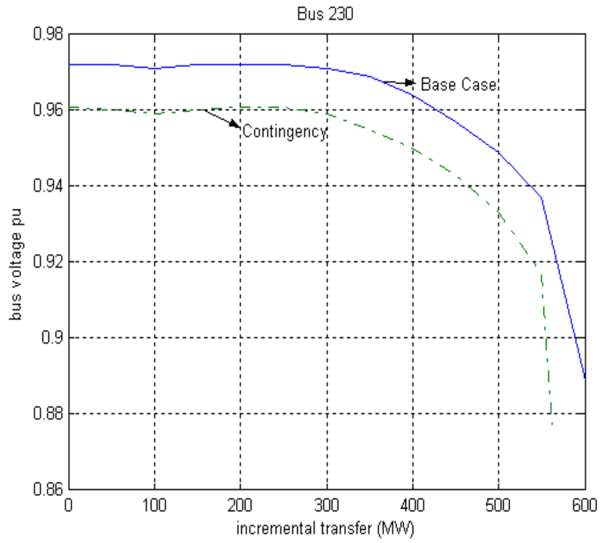

Fig. 4. P-V Curve of Bus 230 at Base and Contingency Cases

By considering the ± 5% of the rated voltage as the upper and lower voltage operating limits, the transfer power limits from Egypt to Jordan during normal and contingency situations are summarized in Table 6. Since the Bus 230 has the lowest power transfer limit, this paper shows its characteristics in all cases.

Table 4. 2 Transfer Power Limit from Egypt

Bus		Bus Voltage Level(KV)	Power Transfer Limit Power(MW)	
Bus No.	Bus Name		Base case	Contingency
230	Ishtafina	33	493.7	400
60	Azraq	33	550	494.5
160	Terwin	33	550	510
24	Subihi	33	553	495
231	Waqas	132	550	485
229	Ishtafina	132	550	480
232	Waqas	33	562	523.5
23	Subihi	132	552.5	494.5
64	Sabha	33	495.5	450

B. Possible Approaches to Increase the Transfer Limit

There are three different possible approaches: 1) construction of additional 400KV overhead line from Aqaba in the south of Jordan to Amman in the north, 2) using UPFC in the 400KV Transmission line connecting Aqaba and Qatrana substations, or 3) connecting STATCOM to the busses having more load and lower voltage, that can be used to increase the power exchange limits among Jordan, Egypt, and Syria. Since the first option is too expensive, this paper only investigates the second and the third approaches to apply FACTS devices in the power systems to improve the operation conditions with less investment.

UPFC in the 400KV Transmission System

According to the characteristics of FACTS devices, it is effective to use the Unified Power Flow Controller (UPFS) in Jordanian power system to enhance its performance when more exchanged power with the other systems is desired.

As shown in the Fig. 5, UPFC is installed in the 400KV transmission system at Aqaba ATP substation.

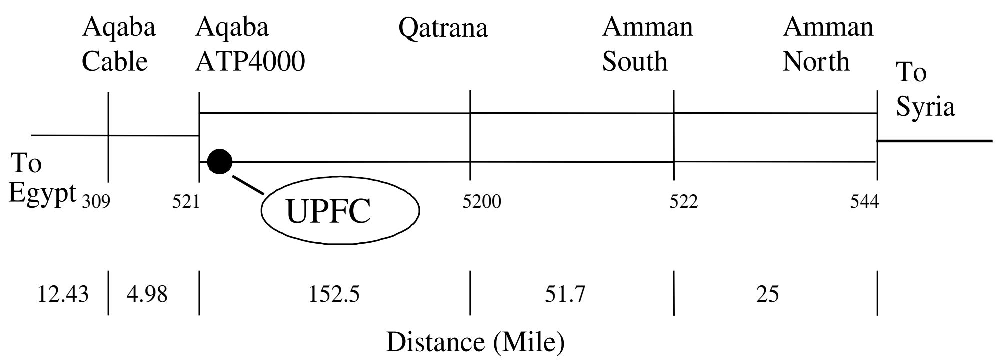

Fig. 5. Proposed UPFC in the 400KV Transmission System

UPFC and Egypt-Jordan Power Exchange Case

Figure 6 shows the improvement of the P-V curve at Bus 230 when the UPFC is applied in the system under the normal operating conditions.

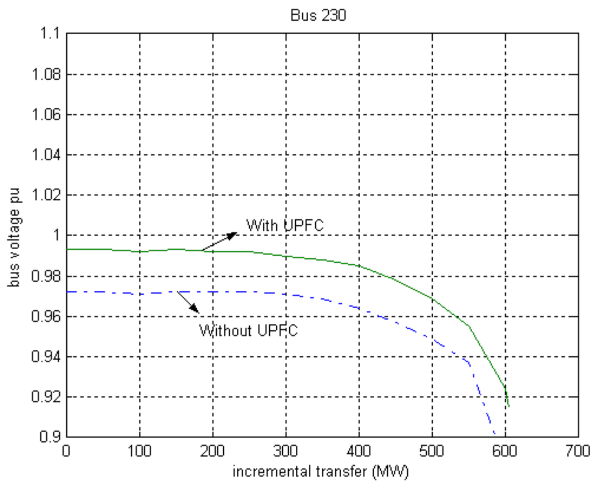

Fig. 6. Power Transfer Limits Comparison (Base Case)

Figure 7 illustrates the improvement of the active power exchanged relation with the bus voltage when the UPFC is applied in the system in case of contingency due to open circuit on the branch between Bus5200 and Bus 522.

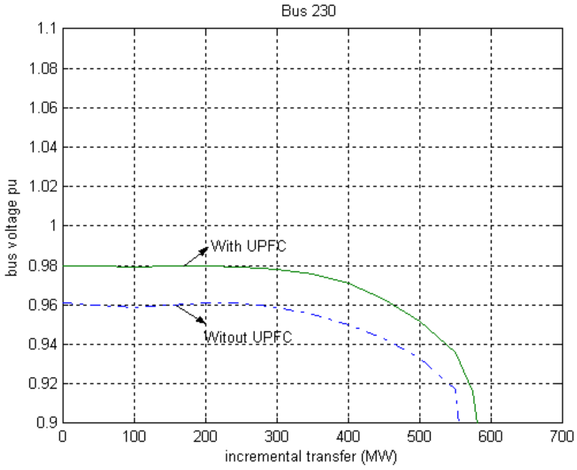

Fig. 7. Power Transfer Limits Comparison (Contingency Case)

UPFC and Egypt-Syria Power Exchange Case

The following subsection shows the response of Jordanian Transmission System in case of power exchange between Egypt and Syria (from Egypt to Syria). The active power exchanged (P) relation with the bus voltage (V) using UPFC in the system as shown in Fig. 5 at base and contingency cases are explicated in Fig. 8 and Fig. 9 respectively.

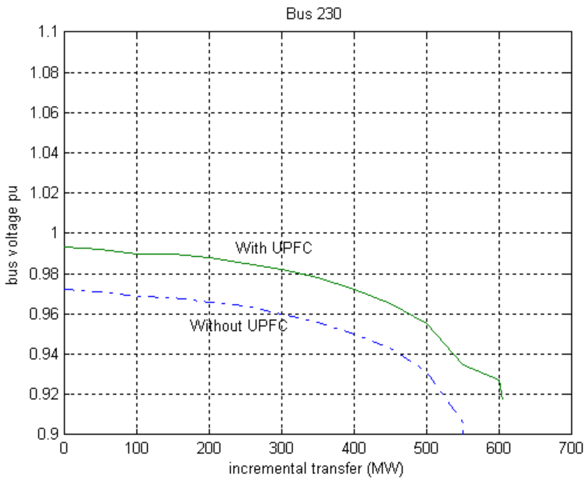

Fig. 8. Power Transfer Limits Comparison (Contingency Case)

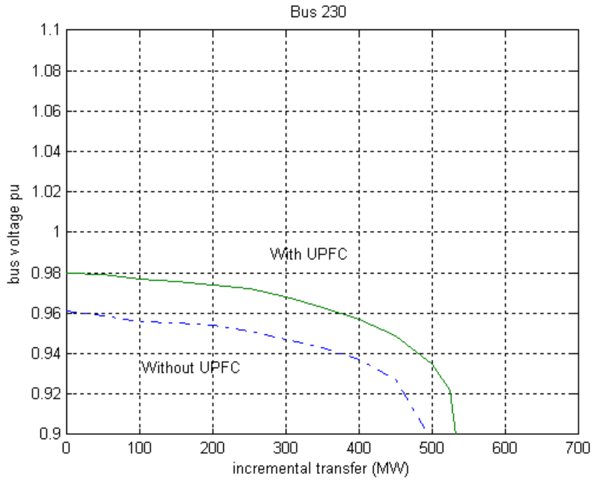

Fig. 9. Power Transfer Limits Comparison (Contingency Case)

Install STATCOM at bus 23 (132KV)

STATCOM controller is an efficient device to improve the steady-state and dynamic performances of the transmission system. It is a shunt connected devices by which the voltage can be regulated by controlling the absorbed or generated reactive power. It is recommended to use STATCOM at the buses having the worst P-V characteristic. The P-V curves of the system are examined when the STATCOM controller is connected at bus 23 (132KV) as shown in Fig. 10.

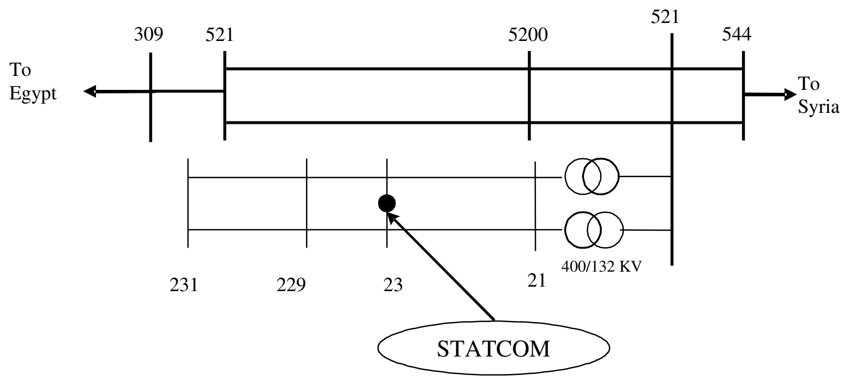

Fig. 10. Proposed Locations for STATCOM

STATCOM and Egypt-Jordan Power Exchange Case

Figure 11 shows the improvement of the power transfer capability at Bus 230 when the STATCOM is applied in the system under normal operation condition.

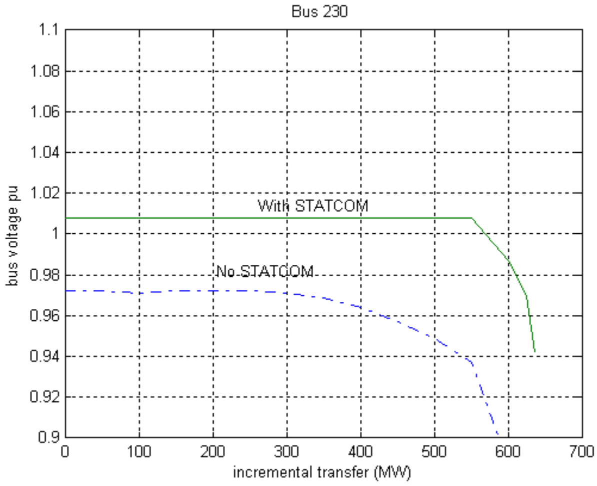

Fig. 11. Power Transfer Limits Comparison (Base Case)

Figure 12 illustrates the relationship between active power exchange level and the bus voltage when the STATCOM is applied in the system in case of contingency due to open circuit in branch (Bus5200 – Bus 522).

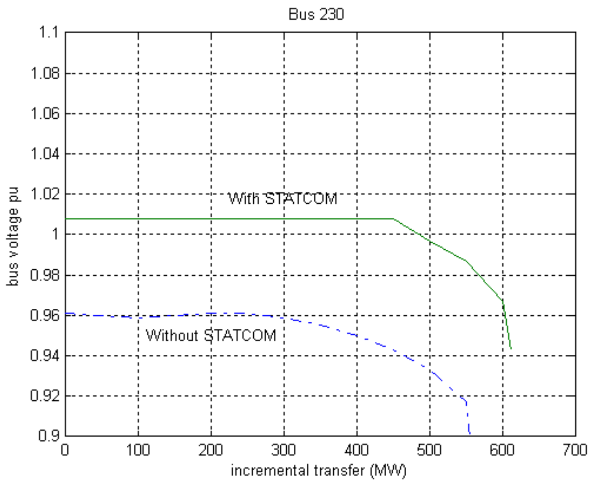

Fig. 12. Power Transfer Limits Comparison (Contingency Case)

STATCOM and Egypt-Syria Power Exchange Case

This section describes the response of Jordanian Transmission System in case of power exchange between Egypt and Syria (from Egypt to Syria). The relationship of the active power exchange (P) and the bus voltage (V) using STATCOM in the system as shown in Fig. 10 under base and contingency cases are explicated in Fig. 13 and Fig. 14 respectively.

IV. CONCLUSION

The Mediterranean Ring project plans to connect electric power transmission grids among the countries that encircle the Mediterranean Sea. Hashemite Kingdom of Jordan reigns over a strategic location among the middle-east countries. It is bordered with Iraq, Syria, Saudi Arabia, Israel, and the Palestinian Authority Territory. Power transfer capabilities between Jordan and its neighboring countries play important role in the effectiveness of the Mediterranean Ring.

This paper studies the impact of FACTS devices on the performance of Jordanian transmission system under different levels of power exchange with Egyptian and Syrian power systems.

According to the study results, both UPFC and STATCOM improve the voltage stability and transfer limit of the transmission system at the selected bus and other buses close to the installation location. More detailed studies are needed to determine the optimal type, sizing, and locations for the FACTS devices.

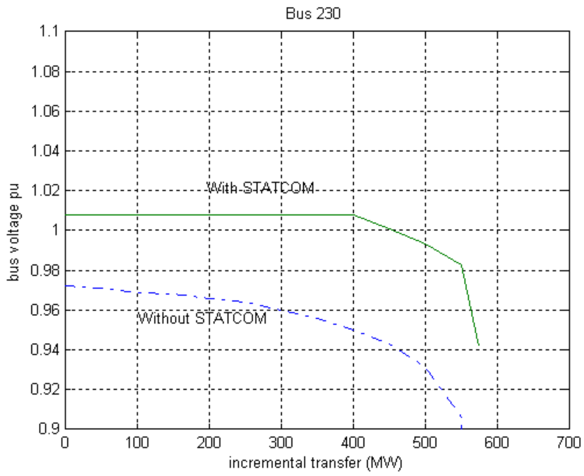

Fig. 13. Power Transfer Limits Comparison (Contingency Case)

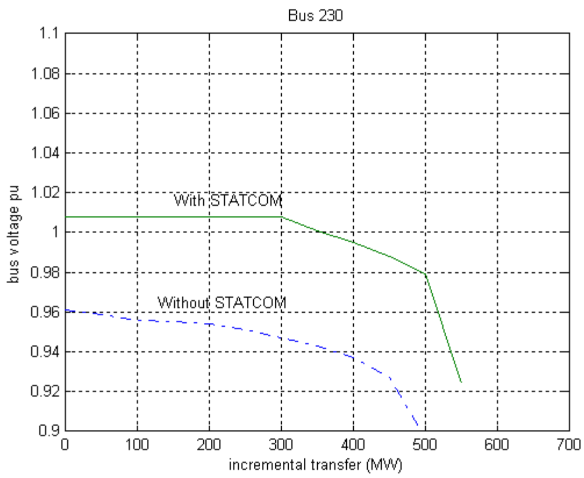

Fig. 14. Power Transfer Limits Comparison (Contingency Case)

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VI. BIOGRAPHIES

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5. Modified Microgrid Concept for Rural Electrification in Africa

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Abstract: With the 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. Many sub-Saharan and sub-Equatorial African countries are poor and have limited electricity infrastructures. A Survey of Energy Resources conducted by the World Energy Council (WEC) in 2004 shows that Africa has more than enough to satisfy all its energy requirements. These include 7.1% of the world's known oil reserves, 7.5% of the gas, 10.6% of the coal and 13% of the hydro. Due to the high cost for the construction of UHV/EHV transmission lines, there are needs to develop a balanced Distributed Generation strategy which takes into account future integration with small, midsize and large regional projects. This paper recommends a bottom up approach through an evaluation of autonomous or non-autonomous modified MicroGrids concept to provide electricity to local residents and which serve as basic building blocks for future system expansion. Issues regarding to the control associated with the integration of Micro Grids to larger systems are addressed.

Keywords: Pan-Africa interconnection, Microgrid, Rural Electrification, Renewable Energy, Distributed Generation.

I. INTRODUCTION

The availability of affordable and reliable energy is one of the most crucial requirements for economic development and modernization of developing countries. This is particularly important in Africa, a continent where the majority of people are still dependent on fuel wood for their energy requirements. With a population of 13.4% of the world and a land area of 15%, Africa has only 2% of the world's industrial capacity. Its per capita income is only 15% of the world average and only consumes 3% of world energy. Today, less than 15% of Africa's population has access to electricity and where much of the available supply is unreliable. A Survey of Energy Resources conducted by the World Energy Council (WEC) in 2004 shows that Africa has more than enough to satisfy all its energy requirements. These include 7.1% of the world's known oil reserves, 7.5% of the gas, 10.6% of the coal and 13% of the hydro. However, the resources are not evenly distributed within the continent. For example, Oil and natural gas are found mainly in the northern and western parts of the continent. Gas usage is limited. Egypt and Algeria produce 98.5 billion cubic meters of Africa's total production of 116.8 billion cubic meters. Almost 96% of the coal is produced in South Africa, Hydro is concentrated mainly on the Congo, Nile, Niger, Volta and Zambezi rivers. Therefore, regional cooperation and integration through energy pooling and cross-border energy trading would help economic development of the continent. This can be achieved through promoting cross-border interconnection of electricity grids and gas pipeline networks and the joint development of new electrical generation projects. However, Interconnecting AC networks will increase the complexity of the system that may affect systems reliability, security, and stability problems due to the interactions of equipment and control actions [1, 2]. Therefore, it is important to have a balanced Distributed Generation strategy which takes into account future integration with small, midsize and large regional projects. This paper goes on to recommend a bottom up approach through an evaluation of autonomous or non-autonomous modified MicroGrids concept to provide electricity to local residents and which serve as primary building blocks for future system expansion. Issues regarding the control associated with the transition and integration of MicroGrids to larger systems are addressed.

II. PAN-AFRICA INTERCONNECTIONS

The continent of Africa has 15% of the world land area and extends from about the 35° north of the equator to about the 35° south of the equator. The total installed capacity of Africa is 94,898 MW in 2003 [1] which for comparison is slightly larger than the size of the Electric Reliability Council of Texas (ERCOT) system. The distribution of generation installation is shown in Table 1. [1 - 5]

Table 1 Installed Generation in Africa

	MW	%	GWH	%
North	28,90 5	30.51	101,688	30.07
South	50,007	52.78	197,481	58.40
West	9,498	10.03	21,190	6.27
East	2,875	3.03	10,083	2.98
Central	3,454	3.65	7,696	2.28
Total	94,739	100.00	338,138	100.00

The New Partnership for Africa's Development (NEPAD) was launched in 2001has committed to merge the various development initiatives being developed by individual African states. Part of that vision was presented to the G8 Heads of State in June 2002 and launched at the World Summit on Sustainable Development in Johannesburg in August-September 2002. Consistent with the value of economies of scale and scarce capital in a competitive global investment climate it is clear that regional cooperation and integration would help economic development of the continent. The electricity sector in particular, has introduced the concept of Pan-Africa Interconnections to facilitate energy pooling and cross-border energy trading as illustrated by the conceptual backbone transmission grid shown in Fig. 1. At present he main development includes Northern Africa (Mediterranean Ring Project), Western, and Southern Africa.

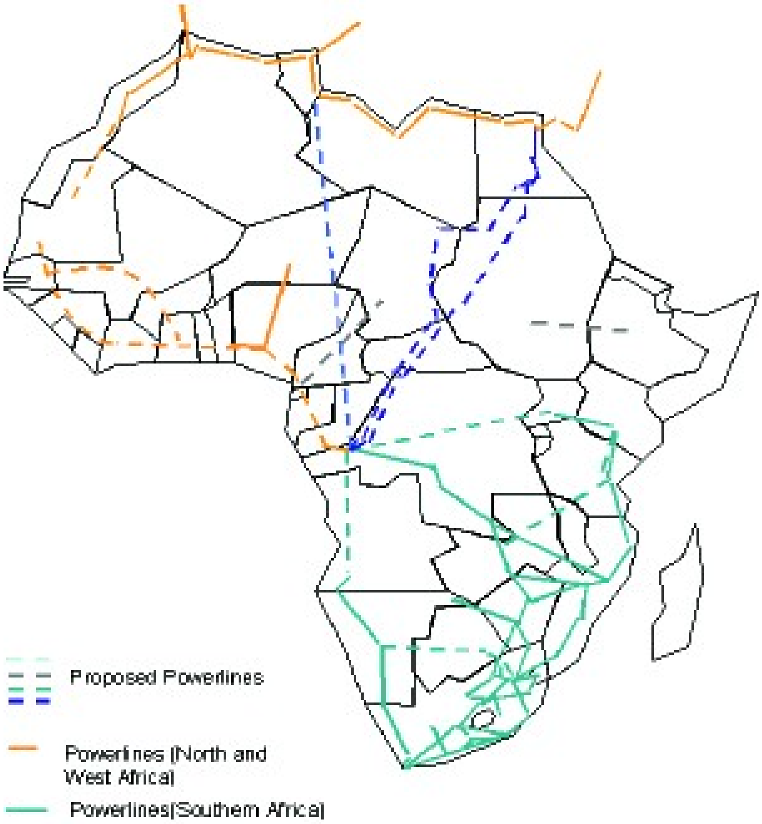

Fig. 1 Pan-Africa Interconnection

III. DISTRIBUTED GENERATION TECHNOLOGIES

The global electricity industry reforms over the last 15 years have moved electricity supply from a central government run generation and transmission system supported by local monopoly suppliers, to an industry where there are competing multiple generators and retailers and a variety of interests in distribution. There is an open investment environment with minimal restrictions on those wanting to invest in distributed generation. Distributed generation, for the moment loosely defined as small-scale electricity generation, is a fairly new concept in the economics literature about electricity markets, but the idea is not new at all. When Thomas Edison started his electrical utility business at Pearl Street Station On September 4, 1882, it only served customers in a one square mile area. Later, technological evolutions allowed for electricity to be transported over longer distances, economies of scale in electricity generation lead to an increase in the power output of the generation units, and reliability concerns lead to the network development. Massive electricity systems were formed with huge transmission and distribution grids and large generation plants.

In the last decade however, technological innovations and a changing economic and regulatory environment have resulted in a renewed interest for distributed generation. This renewed global focus on Distributed Generation (DG) and in particular renewable along with improved generation and control technologies is quite appropriate for the emerging economies throughout Africa. . Combining renewable energy resources (where available) with natural gas or diesel generation can provide reliable power for the small towns and villages. In addition, DG can be made suitable for future grid connection as a basic infrastructure building block.

Hydroelectric Energy

The Fast-flowing water spins turbines to produce electricity. Places with high rainfall and steep mountains are ideal for hydroelectricity. Several large scale hydroelectric generation projects have been developed in Africa. Most hydroelectricity projects require the building of large dams on rivers, which can be very capital intensive and with severe impacts to the environment if not planned with a consensus from various disciplines. When large dams are built the flow of the dammed river is changed radically and large areas of land are flooded, including wildlife habitats and farming land. If possible, run-of-the-river hydroelectric schemes are preferred as they cause less environmental damage. Run-of-the-river schemes divert only part of the river through the plant turbines by harnessing the natural gravity of the river flow to produce electricity. Since there are lots of rivers flowing in the Africa continent, this should be one of the most favorable technologies for the African community.

Biomass Energy

Biomass is plant and animal material that can be used for energy. This includes using wood from trees, waste from other plants (biogases from sugar cane or paddy husk from rice) and manure from livestock. 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.

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

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

Solar Energy

Solar energy is light and heat energy from the sun. Solar cells convert sunlight into electrical energy. There are two main ways of using solar energy to produce electricity. These are through the use of solar cells (photovoltaic) and solar thermal technology. Using solar technologies to generate electricity is, at present, more expensive than using coal-fired power stations, but it produces much less pollution.

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 and several initiatives are underway in North and East Africa.

Wind Energy

Wind energy has gained an extensive interest and become one of the most mature renewable energy alternatives to the conventional fuel-based power generation. The development of wind electricity generation has rapidly progressed over the last decade, largely driven by the public concern about global warming, limited fuel resources, as well as the provision of federal production tax credit. 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.

A large wind turbo generator needs a minimum annual average wind speed of about 15 mile/h. The coast areas in Africa have good potential to use wind generators.

IV. PROPOSED MODIFIED MICROGRID CONCEPT

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. With the help of DOE and other international communities, African countries have launched several rural electrification and distributed generation programs. Sample lists of these programs are presented in Table 2 and 3, respectively.

Table 2 Rural Electrification in Africa [17]

E. Africa	• With over 80,000 systems installed and nearly 20,000 annual sales, Kenya has the highest penetration rate of photovoltaic systems in the world.
N. Africa	• Morocco plans to raise the rate of electrification in rural areas to 60% in 2003 from 21% in 1994. • The government plans to electrify 550,000 rural households and will spend an estimated $153 million yearly to expand power networks to remote and rural areas. • From 1996 to 1998, the country's rural electrification program extended power to 2,728 villages representing 284,000 households.
S. Africa	• Zimbabwe plans to utilize solar power to electrify over 500 districts and rural service points. Each site would receive solar systems with generation capacity of either 100 KW or 500 KW
W. Africa	• The government of Burkina Faso plans to have completed electrification in 48 of the estimated 350 communities in the country by 2010. • Cote d'Ivoire government announced in January 1999 that, with the addition of new generation facilities, power would be provided to 200 villages annually. • The government of Ghana is committed to bringing electric service to every community of 500 or more people by the year 2020. The National Electrification Scheme is planned to proceed in six five-year phases from 1990 to 2020. • Senegal plans to increase electricity availability by 44% in towns and 95% in rural areas by 2004. Under its Program 3000, all Senegalese villages with a population of 3,000 or more inhabitants will be electrified when the project is completed.

Table 3 U.S. Department of Energy (DOE)/National Renewable Energy Laboratory (NREL) Projects in Africa [17]

South Africa	• Department of Minerals and Energy (DME) of South Africa will install at least 2,500 photovoltaic systems in rural areas. • In conjunction with the University of Cape Town and NREL, DME is pursuing hybrid power systems for villages and farms.
Ghana	• Install photovoltaic and hybrid photovoltaic/diesel systems in rural villages.
Egypt	• A collaborative effort to place photovoltaic electricity systems in the Sinai region of Egypt has been proposed by NREL and the Egyptian Rural Electrification Authority.
Uganda	• In conjunction with private partners, DOE is bringing solar electric power to rural areas of Uganda through its Village Power 2000 project.

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

As mentioned earlier, systems planned for local distribution should anticipate future grid connection. This paper proposes the "Olympic Ring" concept which is a metaphor for defining different Micro grids sizes to illustrate possibilities for a 'bottom-up' development. In this paper the aim is to show how leveraging advances in technology while recognizing infrastructure inadequacies can lead to a more efficient optimization of resources. The modern Micro grid power network architecture has incorporated the following power system and power electronics technologies:

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

Depending upon the loading condition and available resources, a single-ring (Fig. 2) or double-ring (Fig. 3) local node could be formulated. Each ring will be equipped with a local node controller for local optimization and control.

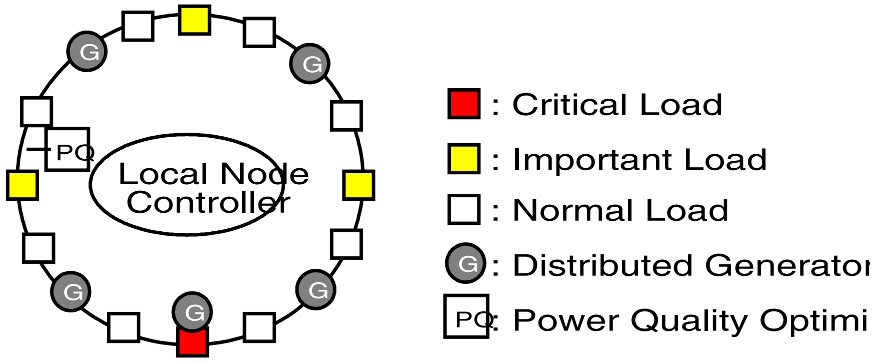

Fig. 2 Formation of Single-Ring Local Node

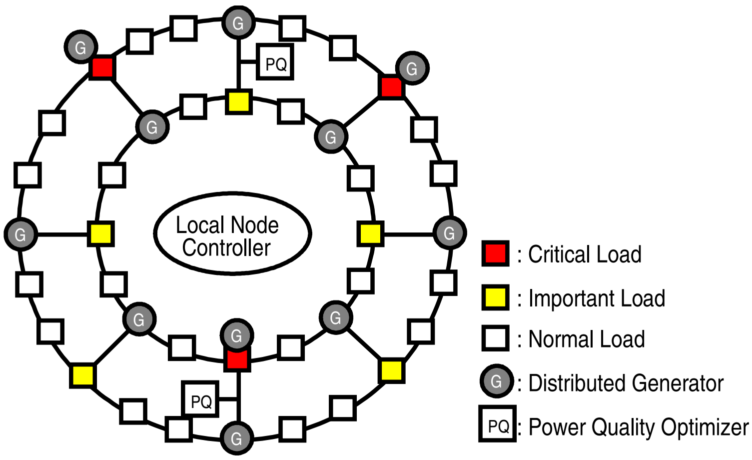

Fig. 3 Formation of Double-Ring Local Node

Clusters of local nodes will then form a super node. As shown in Fig. 4, a ring configuration is preferable since it offers higher system reliability. Super nodes may equip larger scale distributed generation facilities and power quality controllers. The protection schemes between local nodes are similar to the branch protection within the local nodes. Depends upon the operation condition, the super node can be either autonomous or non-autonomous. During the grid connection operation, super node controller will communicate with SCADA/EMS of the local utility or ISO, local node controllers, distributed generators, and PQ optimizers. Super node will serve as basic building block of the future "Smart Grid".

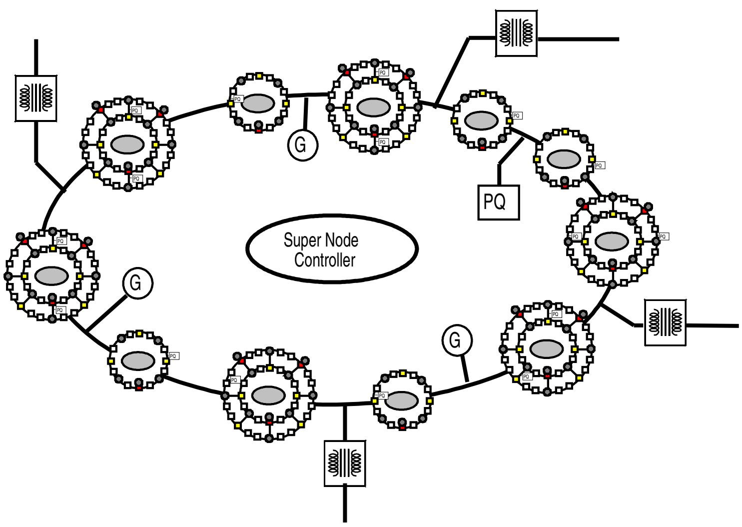

Fig. 4 Formation of a Super Node and Grid Connection

V. REALIZING THE PROPOSED CONCEPT

The proposed systems are designed in a modular fashion so that they can be reconfigured and expanded easily according to the size, need, and available sources of the rural villages. This feature is indispensable for successful multiple deployment. For those institutions and foundations such as The UN Millennium Project and Live 8 , The HIP HOP Nation, ONE.org that represent different levels of sponsorship the "Olympic Design " philosophy of the Microgrid allows for practical customization. For example, a Platinum sponsorship (which could come from single or multiple sources) could provide financial and/or technical support for the electrification of a 400~500 household village; a Gold sponsorship (which could come from single or multiple sources) could provide financial and/or technical support for the electrification of a 300~400 household village, with Silver and Bronze sponsorships providing financial and/or technical support for the electrification of a 200~300 household village etc. Working with NEPAD, the African Union and the assistance of national and international experts, local governments and utilities should provide initial plans and present them to the potential sponsors. A format of co-operation can then be formed to encourage user participation which should lead to an eventual taking ownership of the system by skilled personnel. 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. External sponsorship could then be phased out in five years or less. Local government, utility, and users 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.

VI. CONCLUSION

The G8 Summit at Gleneagles Hotel, Perthshire, Scotland on 6-8 July 2005 has reached agreement for a renewed focus on infrastructure development in Africa. On July 8, 2005, the G8 Leaders met with African leaders to discuss how to accelerate progress towards the Millennium Goals, and in particular for Africa which has the furthest to go to achieve these goals by 2015. Parallel with this effort the Live 8 global event has collected a list of more than 30 million names to support calling for actions to end extreme poverty. While not the first attempt at addressing the social reality on the continent, these latest set of initiatives have been met with great optimism. Kofi Annan, the Secretary General of the United Nations, called the Gleneagles G8 'the greatest summit for Africa ever'. Without any doubt, electricity is among the top priority lists. The following sections have presented an overview of the Africa Energy initiatives and as the importance of planned Microgrids within these developmental initiatives. .

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Wei-Jen Lee (S'85-M'85-SM'97) received his B.S. and M.S. degrees in Electrical Engineering from National Taiwan University, Taipei, Taiwan, in 1978 and 1980, respectively, and a Ph.D. degree in Electrical Engineering from the University of Texas at Arlington in 1985. Since then, he joined the University of Texas at Arlington and currently is the Director of the Energy Systems Research Center and a Professor of the Electrical Engineering Department. He has been involved in research on power flow, transient and dynamic stability, voltage stability, short circuit, relay coordination, power quality analysis, and deregulation of utility industries. He is also involved in research on the design of integrated microcomputer-based monitoring, measurement, control, and protection equipment for electric power systems. He is a senior member of IEEE and a Registered Professional Engineer in the State of Texas

6. Energy Crisis and Development Issues in Africa: A Critical Need of Strategic (Diagonal and Convergent) Approach to Integrate Africa into Global Economy

Dr. Neville S. Arachchige Don, President/CEO, International Research Foundation for Development

Abstract. *Africa is lagging behind and considered as a lost continent. In the face of globalization, Africa cannot claim for the 21st century without integrating its economy into global production and trading system. Africa integration requires a comprehensive approach which ignite rapid structural transformation alleviating poverty and other societal illness, advancement in human development, capacity building and institutional development, reducing social and spatial conflicts and disparities, community empowerment, and the attainment of sustainable societies.*

Energy security can be achieved through a diagonal and convergent approach, which integrate four critical resource factors: water-energy-technology-knowledge. Integration of these critical factors provides the foundation for African development and transformation. Energy security is closely linked with economy, environment, and society. Conversely, energy insecurity produces poverty, deprivation of human development, institutional capacities, and good governance. With the above fundamental tenets, this paper will focus on the followings: 1. overview of the current status of Africa development issues in the light of the energy intensity in terms of production and consumption; 2. examine energy convergence potentials; and 4. emphasize the importance of a comprehensive (diagonal and convergent) approach linking water-energy-technology-, which create a framework to balance economy, environment, and society. Such a comprehensive approach is a must to transform Africa towards a knowledge-based continent and integration into the global economy.

Key words**:** Energy-Technology, structural transformation, diagonal and convergent approach, economy, environment, society, knowledge-based continent

I. INTRODUCTION

Despite vast amount of resource availability, Africa currently suffers from an energy crisis and a water crisis. This paradox reflects in all the other critical components of the development spectrum: Science and technology, information technology, industrial development, agriculture, mining, and forestry, housing and settlements, education. Energy crisis-development link has created a down spiral at every level: national, regional, and the continent. Africa needs a radical departure from its current development strategies and paths in order to achieve a structural transformation and integration into the global economy.

The paper presents a current energy crisis and development issues. The aim of this paper is to emphasize the importance of a strategic approach focusing on energy-development linkage encompassing all the structural components: Water-energy-technology-knowledge to create a knowledge society balancing economy, environment and society.

II. ENERGY CRISIS AND DEVELOPMENT ISSUES IN AFRICA

According to the Energy in Africa 1999 report published by the Energy Information Administration, Africa has the fastest population growth in the world. Population in Africa has more than doubled since 1970 and is growing around 2.7% per year with highly uneven distribution. On average most African countries are sparsely populated. Vast areas of desert are nearly uninhabited with high population concentration in places like Nigeria, the Nile River valley, and the Great Lakes regions. Rapid urban concentration has been the characteristic of population distribution during last several decades. Lack of water and energy infrastructure is largely account for this uneven population distribution.

Africa is the poorest continent on Earth. Average per capita income fell from $646 in 1970 to $576 in 1998. By 2020, African per capita income is expected to increase to $792, which accounts only about 11% of the world average. Economic growth in oil exporting countries is adversely affected when oil prices drop while the sharp increase in world oil prices hurt oil importers. In North Africa, sharp decline in real oil revenues fell between 1980 and the mid-1990s from their peak in the late 1970s and early 1980s. Real GDP also fell in Nigeria, the major oil producing country in sub-Saharan Africa**.**

Despite the energy demand growth has been slightly increasing during the last quarter of the 20th century, the share of world energy consumption is very marginal. African energy consumption per capita and the carbon emissions from fossil fuel have been consistently far lower. Africa has very low levels of per capita electricity consumption. Africa's low level of commercial energy consumption are due to variety of reasons: massively underdeveloped commercial energy resources; poorly developed commercial energy infrastructure including pipelines and electricity grids; low per capita incomes and widespread poverty; level of industrialization; ownership and usage of automobiles; and penetration of appliances; difficulty of importing commercial energy to landlocked countries in Africa; heavy use of biomass in the residential sector (Energy Information Administration, 1999).

Lack of access to commercial energy will effect residential population as well as economic entities, and deprived human development. Both rural masses and poor segment of urban households are heavily relying on biomass-fuel wood or charcoal-to meet its residential energy needs. Intermediate Technology Development Group (ITDG) stated that:

> *Africa's energy crisis keeps people in utter poverty…. 90% cook all their meals on open fires. This is the real energy crisis. According to the World Health Organization, cooking with wood, dung and crop waste poorly ventilated homes is one of the greatest threats to health in developing countries.*

Without modern energy, women and children will die prematurely of indoor smoke inhalation. Brainerd O'Keefe argues that electricity deprivation not only harm rural population but also commercial centers like Lagos. Firms, manufacturing companies and industries, urban households depend on fuel generators to ease the electricity limitations. Refineries do not operate at optimum levels. Nigeria, for instances, loses a billion dollars yearly due to power cuts. Fuel price hikes led to labor strikes that last long enough with severe blow to the economy. Erratic power supply increase the cost of production and create harsh business climate, which scares foreign investment. The absence of modern energy supply in sparked urban migration. All these factors effectively morph into an increase in inflation and unemployment rate (Thought Leaders Nexus, 2004). Energy is a basic requirement for human development. According to world energy assessment report "energy use is closely linked to a range of social issues, including poverty alleviation, population growth, urbanization, and lack of opportunities for women." The last 25 places in the human development index (HDI) are occupied exclusively by African countries (see table 1).

Table 1. The Human Development Index 2003

1. Sierra Leone	14. Malawi
2. Niger	15. Cote d'Ivoire
3. Burkina Faso	16. Tanzania
4. Mali	17. Angola
5. Burundi	18. Senegal
6. Mozambique	19. Benin
7. Ethiopia	20. Rwanda
8. Central African Repub	21. Guinea
9. Congo, Dem. Rep. of	22. Senegal
10. Guinea-Bissau	23. Eritrea
11. Chad	24. Mauritania
12. Angola	25. Djibouti
13. Zambia	

Source: UNDP 2003

Even though the commercial energy production is expected to increase by 2020, it will remain about flat (at around 7%) as a share of the world total, and is distributed unevenly throughout the continent. Around 99% Coal output is in southern Africa (mainly in South Africa), natural gas production is largely concentrated in North Africa (mainly in Algeria, Egypt, and Libya), West Africa (Nigeria), Central Africa (Gabon), and southern Africa (Angola). East Africa has no noticeable level of production of oil, gas, or coal (Energy Information Administration, 1999). Limited investment resources are a constraint for the development of the potential energy sector in different regions in Africa (Energy in Africa). Foreign Direct Investment flow into the region remained highly concentrated, with Algeria, Angola, Chad, Nigeria and Tunisia accounting for half of the total inflows. FDI in natural resources is remarkably insufficient as a force for development in most of the African countries notably with limited linkages to domestic medium and small enterprises (World Investment Report, 2003). Both infrastructure and energy development are concerned, Africa's integration into global and regional economy is playing a marginal role. Africa needs a strategic approach to improve their economy based on energy security-development linkage policies.

III. STRATEGIC (DIAGONAL AND CONVERGENT) APPROACH

This approach aims to device a comprehensive model to implement development strategies to create wealth (physical and human) and reap the benefits to the masses in Africa have resulted in improving quality of life. Any such effort requires structural (physical, economic, technological, political, institutional, cultural, and behavioral) changes to achieve the set goals and objectives. More specifically these changes will alter the total resource structure, power structure, the pattern of relationships and social networks, and ideology (value system) in each locality and community, region, nation, and the whole continent. The basic tenets of this model is holistic (integrated) with cross-sectoral and disciplinary convergence, and a densely device diagonal networks creating new knowledge which harness and generate energy leading to productivity and efficiency as an engine of the wealth creation (physical and human). This strategic approach includes all sectors of the three major pillars of sustainable development: economy, environment, and society. Water, energy, technology, and knowledge) must be the key components of the national and sectoral, and micro and macro planning within a broad sub-regional, regional, and continental framework. The critical step of this approach is to recognize the energy-development diagonal linkages and parameters in comprehensive terms such as energy infrastructure, access to energy, poverty alleviation & human development, community empowerment, institutional capacity building and sustainable governance, peace and social stability, and physical economic growth. This model assumes non-linear, but interactive-diagonal linkages (see fig 1).

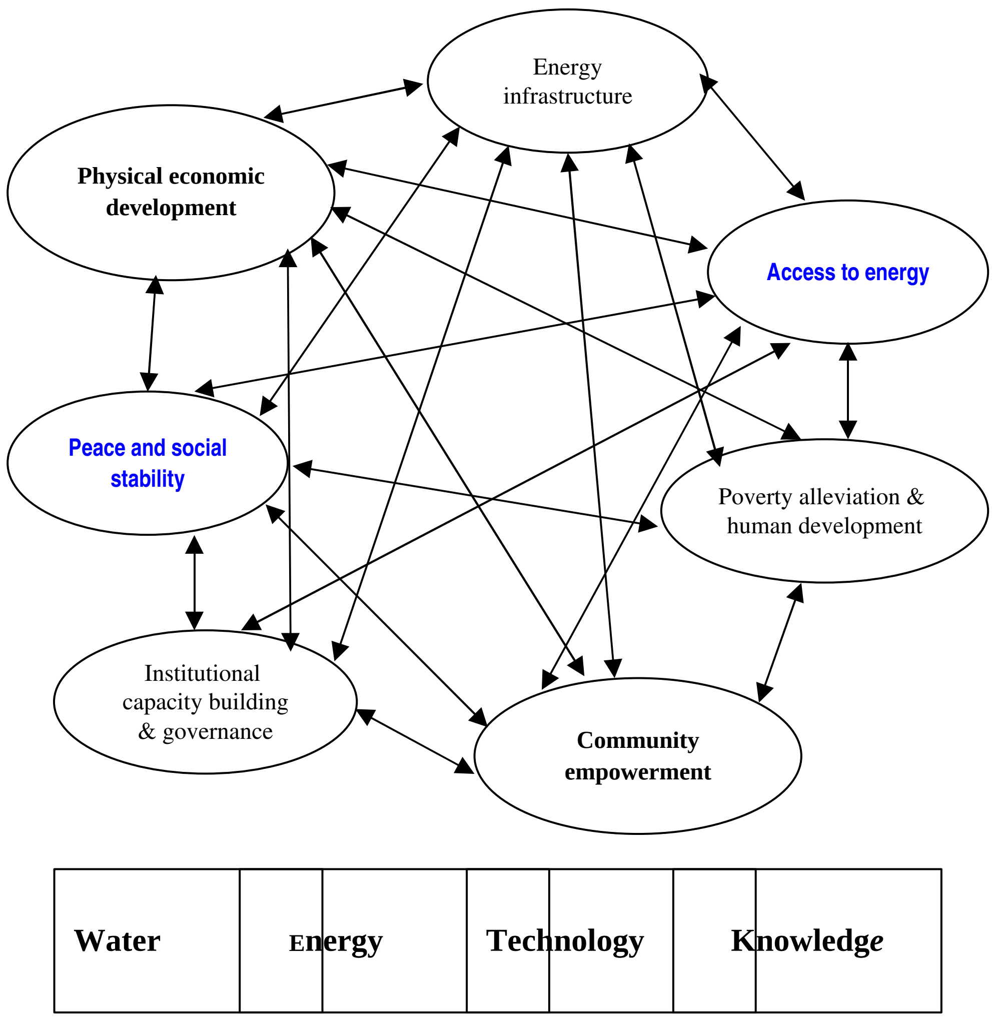

Fig. 1. Energy-Development Diagonal and Convergent Model

A. Components of Strategic Approach: Water-Energy-Technology-Knowledge

Strategic approach must address critical issues pertaining to supply of fresh water, energy, technology, and creation of knowledge (WETK). Harnessing of freshwater, energy generation (both commercial and renewable energy), application of science and technology, establishment of knowledge-based society are the first layers of foundation of the development of African Continent. They are the critical need for the entire ecosystem and the sustenance of the productive capacities of all the sectors: mining, forestry, agriculture, manufacturing, housing, employment generation, poverty reduction, improvement of health and education, tourism, and maintaining social cohesion and stability. The sectoral development in an integrated manner will provide the basis for human development and community empowerment in its entirety. Human development and community empowerment need to be defined as opportunities for maximization of human potentials and expansion of individual and group opportunities to engage in decision-making and participation in community and civic affairs. This engagement will provide a meaningful framework to crystallize and transform tacit knowledge into explicit knowledge, multiply the generation of new knowledge. A radical intellectual departure is a prerequisite for this new approach. Thus, convergent and diagonal interactive density is a fundamental conceptual and methodological shift in this approach.

i. Water and Power Generation

Development Africa stated that African continent is suffering from a virtual economic paradox: a shortage of water amidst potentially plentiful supplies. South Africa's Minister of Water Affairs and Forestry said, "in spite of a few large rivers like the Congo and the Nile, 21 of the world's most arid countries, in terms of water per person, are located in Africa." Africa is the least developed continent with respect to water resource infrastructure. According to the Stockholm International Water Institute (SIWI), Africa faces the most daunting challenges in its efforts to reach the U.N. Millennium Development Goals (MDGs) on water and sanitation
(http://www.ipsnews.net/africa/nota.asp?idnews=30001)

The critical impact of water scarcity needs to be addressed in relation to all the sectors of development in African continent. Therefore, it is necessary to emphasize the urgent need for an integrated water resource management, trans boundary water collaboration and governance. Regional cooperation for hydroelectric power generation by water could play a significant role in providing power regionally to central and southern Africa. Buyelwa Sonjica, addressing water experts and representatives of NGOs in Geneva, emphasized the linkage between water and democracy and stated "the progress that is currently being made towards peace and democratization of the Democratic Republic of Congo (DRC) can unlock the hydropower potential of the Congo River, and this can be the key to unlock the economic potential of the whole African continent."
(DevelopmentAfrica- http://www.ipsnews.net/Africa/nota.asp?idnews=30001).

ii. Commercial Energy and Renewable Energy

While recognizing new investment in commercial energy-oil, natural gas, and coal-renewable energy is the appropriate source, which includes modern biomass, small hydro, geothermal, wind, and solar, and ocean tidal power. Dr. Brainerd O'Keefe, the director of BioEnergies Corporation, recognized alternative energy sources as the key to ending African energy crisis, and he argues that

> *Technology is proving itself an infinite resource as it transforms the future energy…These renewable energy technologies include fuel cells. Fuel cells are the most efficient, clean and reliable source of electricity. They generate power from the chemical reactions that occur when hydrogen and oxygen combine. Vehicles can be powered and heat and light provided for houses and buildings. Also solar or photovoltaic cells use energy from the sun converting it into electric energy. Wind turbines are cost effective. They generate energy from wind. Geothermal systems utilize the earth heat as its chief energy source. Biogas/biomass are renewable energy technologies that utilize nature waste (plants and animals). The beautiful thing about these systems is that their energy source is renewable unlike conventional oil and coal deposits. They cannot be exhausted (Thought Leaders Nexus, 2004).*

Intermediate Technology group emphasize the importance of decentralized energy technologies such as microhydro, efficient kilns for use by small scale enterprises, improved biomass stoves for commercial production which is important for community development in rural Africa. Furthermore, based on ITDG projects in East Africa, they identified ‘clear need to harness and develop the synergy of energy development organizations to enhance the use of technology that generates income and contributes to reduction of poverty.’ ITDG-EA projects include rural stove commercialization which provide household energy, the solar lantern project which provide high quality light and a combination of light and radio, the smoke project which seeks solution for indoor air pollution, the hurricane lamps project helps to create more jobs and increase incomes for micro enterprises, community micro-hydro project which is expected to generate 18 kw that will cover a radius of 3 km. The power generated is supposed owned by the local community (http://www.itdg.org/?d=region_east_africa_energy).

It is well document that the need for energy information system to map energy resources and usage patterns to take informed decisions which ensure appropriate energy development both at national and regional level balancing environment, economy, and society. This can be done only through an integrated African energy effort. To this effect, the establishment of African Energy Commission (AFREC) has been agreed by the African Heads of States. This effort is expected to bring ‘regional co-operation and provide policy-makers with the tools to accelerate the penetration of modern services across the continent’ (Claude Mandil, The International Energy Agency). Effective regional co-operation with sound policy instrument can be build upon a comparative energy data system which use GIS for detailed mapping of energy resources in terms of economic sectoral development needs and decentralized energy requirements which facilitate human development and community empowerment. This will lead to better sharing of information on energy requirements, availability, and best practices of energy consumption across the continent at national, regional, and micro-community levels

iii. Science and Technology

The third important component of this approach is science and technology. The traditional specialized approach disciplinary knowledge has limited value. Therefore, it is necessary to create a converging framework for cross-disciplinary applications and generating new knowledge for the energy systems and development models. This convergent approach will allow hybridization of modern and traditional appropriate technologies for better application. Most African countries have very underdeveloped levels of science and technology capacity in terms of research and development, and institutional frameworks.

Comprehensive policies and action strategies at the sub-regional level are of paramount importance in addressing the issue of underdeveloped nature of science and technology. Short-term, mid-term, and long-term strategies for public-private venture capital both at sub-regional and regional levels need to be adapted. These strategies should consist of a convergence of water, energy, technology, and knowledge within a sustainable framework that drive innovative products and services applicable to: agriculture, mining, forestry, industry, housing and settlements, infrastructure and transportation, health and sanitation, food security, land use management and planning, telecommunication and information technology. Furthermore, African sub-regional networks and collaborations should create a conducive environment, and attract foreign investors with joint venture capital for energy sector.

Most of the foreign aid needs to be channeled to science education, and institutional capacity building related to all development sectors both at the national and sub-regional levels. The European Union, G8 countries, and other donor countries need to adopt an approach of genuine support establishing special funding mechanisms for the development of science and technology to achieve sustainable development generating efficient energy systems. The UN and its agencies such as UNESCO, UNDP, UNEP, and UNIDO should direct their projects and programs with added strength in finance, expertise, and training, particularly to facilitate the development of science and technology in least developed countries in Africa.

iv. Knowledge-based Society and Strategies

Globalization along with information revolution demands a new form of society known as the knowledge-based society. Therefore, knowledge-based society should create an environment to increase a broad based knowledge ownership of the critical masses. Beyond the traditional formal education systems, community based and development oriented knowledge generation need to be established. Access to information technology is a paramount important at community level to bridge connection between tacit and explicit knowledge. Community based research-policy-action framework need to be introduced.

Rural-electrification, and use of other renewable energy to generate power for communities is an essential prerequisite for information technology application and to create knowledge society and proper knowledge management. Transformation of tacit knowledge into virtual reality and cross-community sharing will empower local communities throughout African continent. Cultural innovation and integration along with community scientific culture are potential endeavors in a knowledge-based society. This local knowledge-based communities need to be connected across national, regional, and international boundaries for cultural enrichments, openness, exposure, and sustainable governance, and creation of physical wealth balancing environment, society, and economy. E-community development strategy (http://www.irfd.org) will encompass the full spectrum of human potentials focusing on Millennium development goals (MDGs).

IV. CONCLUSION

Africa is suffering from a development paradox: energy crisis-underdevelopment down spiral amidst potentially abundant resources. African leaders are fully aware of this situation and began to find way out of this paradox. Africa needs to depart radically from its current paths in order to transform and integrate the continent into global economy. A strategic approach (diagonal and convergent) needs to be adopted for this transformation

Energy security-development linkage can be strengthening through integrating four critical resource factors: water-energy-technology-knowledge (WETK). This integrating framework assumes a balance between economy, environment, and society. Energy-development linkage through WETK encompasses fully access to energy and information technology, human development and poverty alleviation, community empowerment, peace and social stability, institutional capacity building and governance, and physical economic development. This diagonal and convergent strategic approach will provide the basis for knowledge-society, structural transformation and lead African continent toward integration into global economy.

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VI. BIOGRAPHY

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7. Variable Frequency Transformer – An Overview

Arezki Merkhouf, *Member, IEEE,* Sanjoy Upadhyay, *Member, IEEE,* and Pierre Doyon

Abstract-- Variable Frequency Transformer (VFT) is a controllable bi-directional transmission device that can transfer power between asynchronous networks. The construction of VFT is similar to conventional asynchronous machines. Electrical power is exchanged between the two networks by magnetic coupling through the air gap of the VFT. This paper gives an overview of the VFT.

Index Terms-- interconnected power systems, asynchronous rotating machines, power transmission, load flow control, HVdc substations, flexible ac transmission system, phase shifting transformer, phase angle regulator, rotating transformer.

I. INTRODUCTION

The world's first VFT has been successfully installed, tested, commissioned and started commercial operation in early 2004 [1]. Although the VFT concept is new, VFT equipment is comprised of well-established hydro-generator, dc motor, and variable-speed drive technology.

The variable frequency transformer (VFT) is essentially a continuously variable phase shifting transformer that can operate at an adjustable phase angle. A direct application of a VFT is as a phase shifting transformer connecting two power systems operating at the same frequency and controlling the power flow. A phase shifting transformer (conventional or in conjunction with power electronic devices) is used to control real power flow along a transmission line and have their respective drawbacks [2]. The VFT, when used as a phase shifting transformer, overcomes all these difficulties.

The versatility of the VFT, however, lies in connecting two systems that are asynchronous. The conventional method of connecting two such asynchronous systems is to use back-to-back high voltage direct current (HVdc) connection. The technical performance of these two methods is comparable. In [3], such an application of the VFT has been reported.

II. VARIABLE FREQUENCY TRANSFORMER OVERVIEW

The core technology of the VFT is the rotary transformer (also known as "Runkle Machine" within GE) with three-phase windings on both rotor and the stator [4, 5]. A three phases collector system conducts current between the three-phase rotor winding and its stationary busduct. The two separate electrical networks are connected to the stator and rotor respectively. Electrical power is exchanged between the two networks by the magnetic coupling through the air gap. A drive motor and a variable speed drive system is used to apply torque to the rotor of the transformer and adjust the rotational position of the rotor relative to the stator, thereby controlling the magnitude and direction of the power flow through the VFT. Fig 1 shows the core components of the VFT.

Fig. 2 illustrates a conceptual system diagram of the VFT. Conventional transformers are used to match the transmission voltage to the machine voltage. Shunt capacitors are used to compensate for the reactive magnetizing currents.

As with any other AC power circuit, the real power flow through the rotary transformer is proportional to the phase angle difference between the stator and the rotor. The impedance of the rotary transformer and AC grid determine the magnitude of phase shift required for a given power transfer. Reactive power flow through the VFT is determined by the series impedance of the rotary transformer and the difference in magnitude of voltages on the two sides.

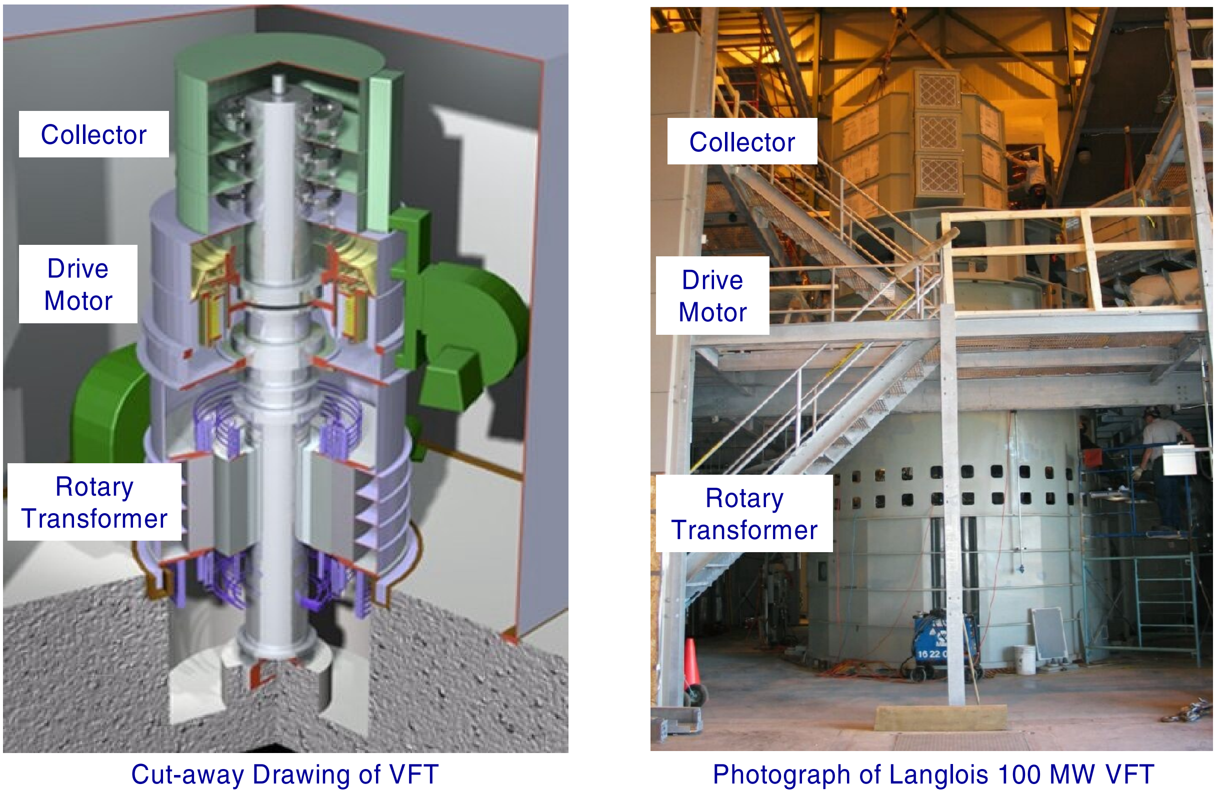

Fig. 1. Core components of the VFT.

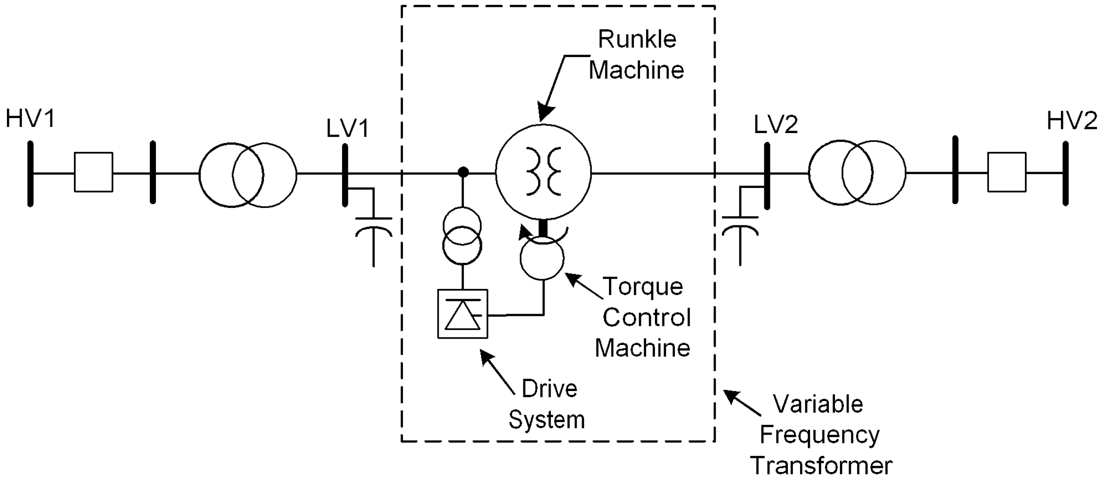

Fig. 2. System diagram of the Variable Frequency Transformer.

Power transfer through the rotary transformer is a function of the torque applied to the rotor. When the systems are in synchronism, the VFT rotor remains in the position in which the stator and rotor voltage are in phase with associated systems. In order to transfer power from one system to other, the rotor of the VFT is turned out of this initial position. If torque is applied in one direction, then power flows from the stator winding to the rotor winding. If torque is applied in the opposite direction, then power flows from the rotor winding to the stator winding. Power flow is proportional to the magnitude and direction of the torque applied. The motor and drive system are designed to continuously produce torque while at zero speed (standstill). If no torque is applied, then no power flows through the rotary transformer. When the two systems are no longer in synchronism, the rotor of the VFT will rotate continuously and the rotational speed will be proportional to the difference in frequency between the two power grids. During this operation the load flow is maintained. The VFT is designed to continuously regulate power flow with drifting frequencies on both grids. Regardless of power flow, the rotor inherently orients itself to follow the phase angle difference imposed by the two asynchronous systems.

Power systems are subject to various disturbances resulting in frequency and voltage deviations. To keep a constant power transfer, the VFT control system must constantly take action and compensate for any frequency variations across the two asynchronous networks to maintain the relative position of the rotor with respect to the stator. A closed loop power regulator maintains power transfer equal to an operator set point. The regulator compares measured power with the set point, and adjusts motor torque as a function of power error. To ensure proper behavior for normal system operation and sufficient robustness during system events, the VFT stations are designed for a large range of system conditions – normal, abnormal and extreme. Fig. 3 shows the variation of the power and frequency of the VFT during actual operation and overcoming a local disturbance successfully.

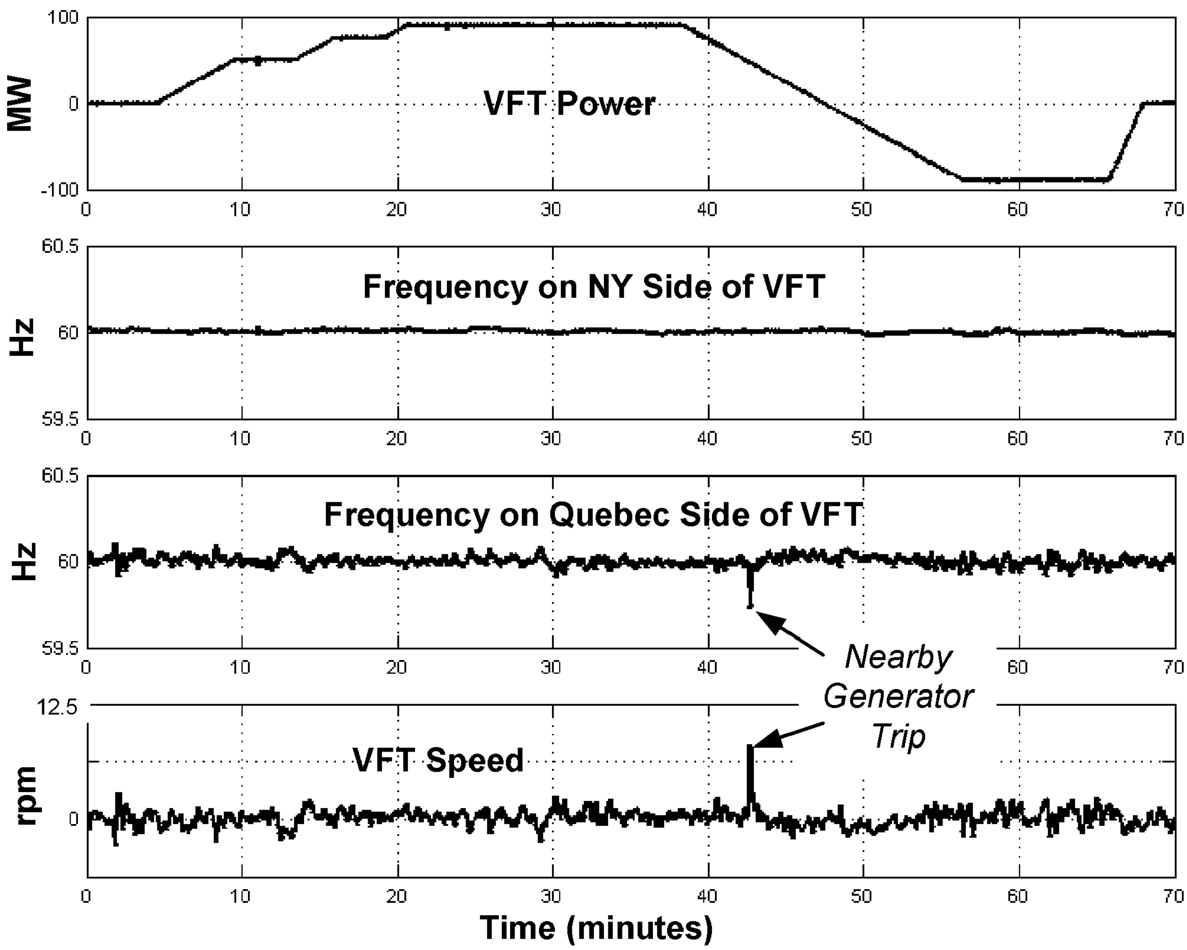

Fig. 3. VFT power ramps at Langlois substation during asynchronous operation with the New York and Quebec power networks.

III. MECHANICAL DESIGN OVERVIEW

The mechanical aspects of the machine were tailored to the vertical arrangement of the VFT rotary system. It is composed of three main components – (a) Rotating transformer (b) Drive motor and (c) Collector. The various components are shown in Fig. 1 and in Fig. 4.

The three phases collector is at the top of the rotary system. The collector comprises of conventional carbon-brush technology on copper slip rings. The collector rings are connected to the rotor windings via a three phases bus that runs through the hollow shaft. Fig. 5 shows the site assembly of a typical collector system. The drive motor is a conventional dc motor. The rotating components, since they have very little self-cooling capability because of the low rotational speed, are force-air cooled.

The inertia of the total rotary system is rather large. Typically, in per-unit on a 100 MVA base, it has an equivalent H-factor of about 26 pu-sec. This large inertia helps to maintain stability during grid disturbances.

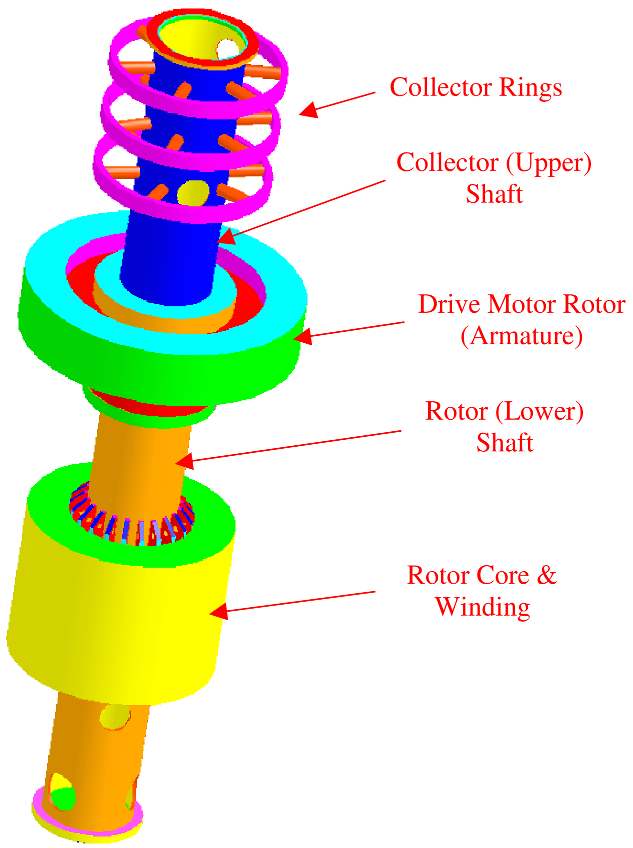

Fig. 4. VFT rotating components.

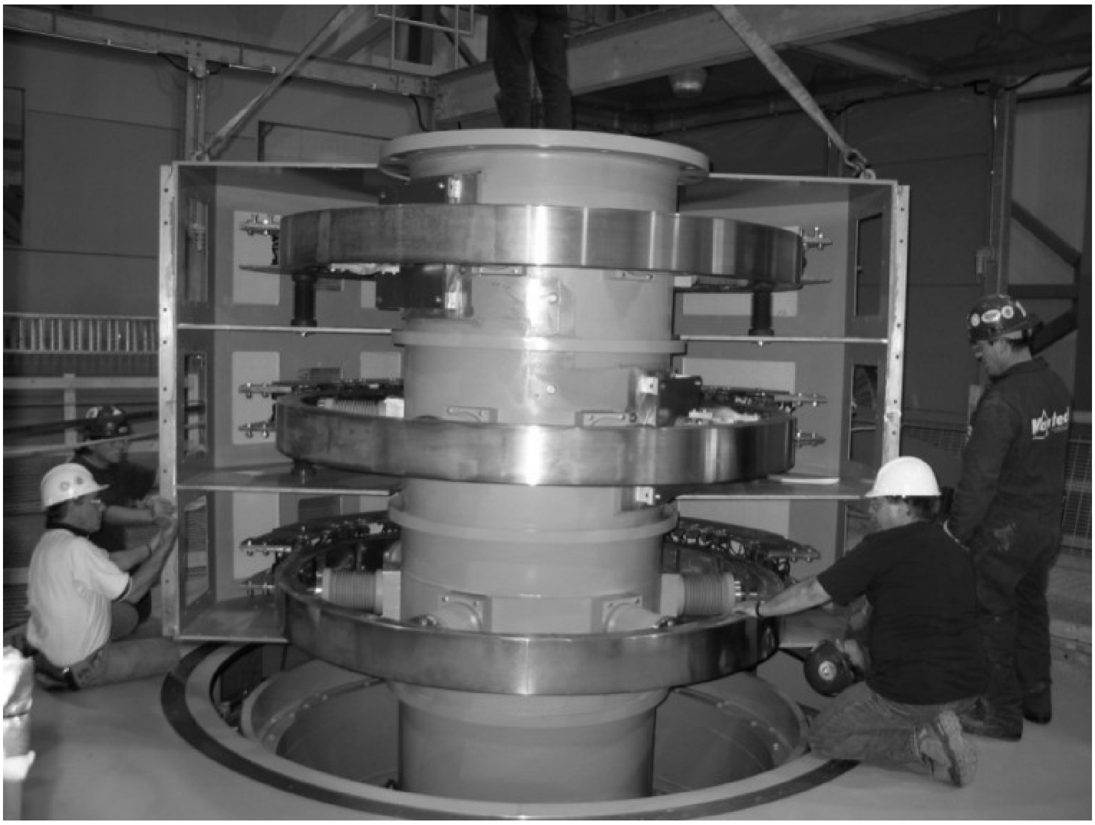

Fig. 5. A typical assembly of VFT three phase collector.

IV. VFT BASIC THEORY

The power transfer through the VFT can be approximated as

$$P_{VFT} = \frac{V_s V_r}{X_{sr}} \sin\left(\theta_s - (\theta_r + \theta_{rm})\right) \text{, or}$$

$$P_{VFT} = P_{XMAX} \sin \theta_{net} \qquad (1)$$

where,

P_{VFT} = Power through VFT from stator to rotor,
V_s = Voltage magnitude on stator terminal,
V_r = Voltage magnitude on rotor terminal,
X_{sr} = Total reactance between stator and rotor terminals,
θ_s = Phase-angle of ac voltage on stator, with respect to a reference phasor,
θ_r = Phase-angle of ac voltage on rotor, with respect to a reference phasor,
θ_{rm} = Phase-angle of Runkle Machine rotor with respect to stator,
θ_{net} = $\theta_s - (\theta_r + \theta_{rm})$, where the phasor relationships are indicated in Fig 6 and
$P_{XMAX} = \frac{V_s V_r}{X_{sr}}$, maximum theoretical power transfer possible through the VFT in either direction

which occurs when the net angle θ_{net} is near 90° ($\frac{\pi}{2}$ radians) in either direction.

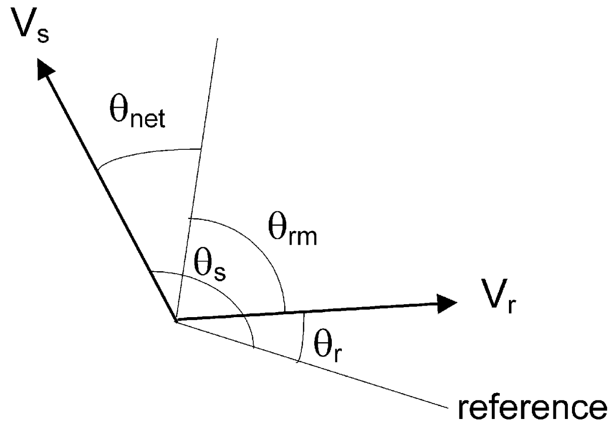

Fig. 6. Runkle Machine phasor relationship.

For stable operation, the angle θ_{net} must have an absolute value significantly less than $\frac{\pi}{2}$ radians, which means that power transfer will be limited to some fraction of the maximum theoretical level given by (1). Within this range, the power transfer follows a monotonic and nearly linear relationship to the net angle, which can be approximated by:

$$P_{VFT} \simeq P_{XMAX} \ \theta_{net} \ . \qquad (2)$$

The power flow equations below are based on an ideal Runkle Machine, with negligible leakage reactance and magnetizing current. Further, for clarity, only real power flow is addressed.

Fig. 7 illustrates a VFT system connected between two power systems, with a third power system providing a power sink or source for the torque-control drive system.

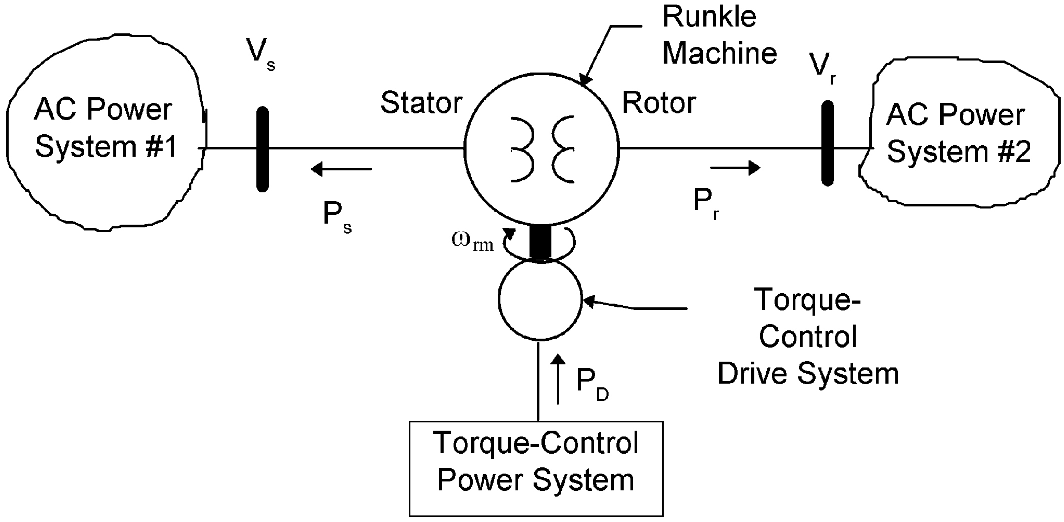

Fig. 7. VFT real power flow diagram.

The power flow directions shown in Fig. 7 are based on generator convention with positive sign indicating power flowing out of the machine windings and into the shaft through the drive system. The actual power flow direction may be either positive or negative depending on the operating condition.

Power balance requires that the electrical power flowing out of the stator must flow into the combined electrical path on the rotor and the mechanical path to the drive system:

$$P_s = P_D - P_r \quad (3)$$

where,

P_s = electrical power out of stator windings
P_r = electrical power out of rotor windings
P_D = mechanical power to the torque-control drive system, eventually appearing as electrical power exchanged with the power system to which the drive system is connected.

Since the Runkle Machine behaves like a transformer, ampere-turns must balance between rotor and stator:

$$N_s * I_s = -N_r * I_r \quad (4)$$

where,

N_s = number of turns on stator winding,
N_r = number of turns on rotor winding,
I_s = current out of the stator winding and
I_r = current out of the rotor winding.

Both the stator and rotor windings link the same magnetic flux. However, the frequency differs so the voltage will also differ by the same ratio:

$$V_s = N_s * f_s * Y_a \text{ and} \quad (5)$$
$$V_r = N_r * f_r * Y_a \text{ ,} \quad (6)$$
$$\text{or, } V_r / N_r = V_s / N_s * f_r / f_s \quad (7)$$

where,

V_r = voltage on rotor winding,
V_s = voltage on stator winding,
f_s = electrical frequency on stator winding (Hz),
f_r = electrical frequency on rotor winding (Hz) and
ψ_a = air-gap flux.

The nature of the machine is such that in steady state, the rotor speed is proportional to the difference in the electrical frequency on the stator and rotor windings,

$$f_{rm} = f_s - f_r \text{ , and} \quad (8)$$
$$\omega_{rm} = f_{rm} * 120 / N_P \quad (9)$$

where,

f_{rm}	= rotor mechanical speed, in electrical-frequency units (Hz),
N_P	= number of poles in Runkle Machine and
ω_{rm}	= rotor mechanical speed in rpm.

Combining the above relationships gives the power exchanged with the drive system as

$$P_D = P_s + P_r$$
$$¿ V_s * I_s + V_r * I_r$$
$$¿ V_s * I_s - \left(N_r * V_s / N_s * f_r / f_s\right) * \left(N_s * I_s / N_r\right)$$
$$¿ V_s * I_s * \left(1 - f_r / f_s\right)$$

or, $P_D = P_s * \left(1 - f_r / f_s\right)$. (10)

The torque produced by the drive system (T_D) is

$$T_D = P_D / f_{rm}$$
$$¿ V_s * I_s * \left[\left(f_s - f_r\right) / f_s\right] / \left(f_s - f_r\right)$$
$$¿ V_s * I_s / f_s$$
$$¿ N_s * f_s * Y_a * I_s / f_s$$

or, $T_D = N_s * I_s * Y_a$. (11)

It should be noted that the drive system torque T_D is independent of rotational speed, being only proportional to stator current and air gap flux. Since the machine will operate near constant flux, this means that torque is proportional only to stator current. Hence, if the stator frequency is constant, then the torque is proportional to through power.

V. TECHNICAL HIGHLIGHTS

The advantages of VFT over other competing technologies are:

a. It provides a simple and controlled path between electrical grids, permitting power exchanges that couldn't previously be accomplished owing to technical constraints such as asynchronous boundaries or congested systems.
b. A VFT substation has a smaller footprint; a complete 100 MW VFT substation should occupy a space of about 30 m x 80 m as compared to a similar conventional HVdc site requiring typically 2 to 3 times that space.
c. Unlike power-electronic alternatives, the VFT produces negligible harmonics and cannot cause undesirable interactions with neighboring generators or other equipment on the grid.
d. The first VFT prototype was validated and expected performances were demonstrated in service leading to confidence in future application studies. The behavior obtained during

commissioning tests demonstrated that this new technology is an effective way of transferring power between asynchronous systems.

VI. CONCLUSION

The VFT has proven itself to be a viable alternative to back-to-back HVdc converters for the interconnection of asynchronous power grids and as replacement for phase shifting transformers.

Future application of the VFT would be to utilize the dual ability to control the phase as well as to compensate for the frequency variation. This could be used to operate pumps or hydro turbines closer to their maximum efficiency conditions. It could also be used to stabilize or absorb load swings in a power system, which would permit operation with a lower spinning reserve.

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VIII. BIOGRAPHIES

Arezki Merkhouf (Member IEEE) B.Sc. Eng.’90, University of Algeria; M.Sc.’92 University of Pierre and Marie Curie, France; Ph.D.’1999 University of Sherbrooke (Quebec), in electrical engineering. In June 2000, he joined GE Energy (Hydro), where he is a member of R&D team. His research activities include analytical and numerical simulation of large rotating electrical machines, numerical and analytical computation of electromagnetic fields, variable frequency transformers, power electronic and drives.

Sanjoy Upadhyay (Member IEEE) B.E.E ’93, Jadavpur University, Kolkata, India; M.Sc. ’01 University of Saskatchewan, Saskatoon, Canada in electrical engineering. He joined GE Energy in 2000 as a member of the hydro generator design team. He is presently involved in system design as relating to hydro power plants. Prior to joining GE he worked for DCL, a consultancy firm in Kolkata, India. His research interests include electrical machines, power electronics, variable frequency transformers, power system dynamics and hydro system dynamics.

Pierre Doyon graduated from L’Université Laval, Quebec City, Canada (1987) and joined GE Energy (Hydro) in 1988. He later obtained a master`s degree from University of Toronto, Canada. His employment experience also includes the Canadian Armed Forces. His fields of interest include hydro generators, variable frequency transformers and optimization techniques.

8. Human Resources Developments in HVDC Engineering for Continental Grid Application (Invited Discussion+)

P. Naidoo*, D Muftic, R Vajeth**, I Ijumba***, P Pillay**** and A F Zobaa*****

ABSTRACT

The power transmission grid from Cape to Cairo has been modeled in power system forward planning studies. With large-scale distributed generation sources, it is shown that HVDC transmission technology provides the bulk point-to-point power transfers over the long distances.

HVDC technology requires the detailed knowledge:

- of the electrical physics of transmission line engineering,
- of high voltage power equipment dielectric insulation,
- the presence of high currents and importance of the cooling for the power electronics,
- the need for control systems engineering for both scheme protection and power control, and
- an integrated power system operations strategy for areas of weak and strong HVAC optional power flow paths.

To build the power system infrastructure across continental Africa will be the easy output. The difficult and complex output will be in the operations, maintenance and long-term sustainability of the schemes. Based on the historical performance of the African HVDC schemes of Inga – Shaba 500 kV and Cahora Bassa – Apollo 533 kV, likely causes of faulting and recommended design and management strategies are provided.

Whilst certain design strategies could lower fault incidence; the forward skilling and training and development of local engineers and technicians is a continental priority. The paper shares work done at the Universities of Cape Town, Cairo, Kwa Zulu Natal, Eskom and Trans Africa Projects and calls for a greater contribution from other Utilities, Universities, Institutes and Manufacturers of Power Equipment.

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9. Feedback Report on the Short Term Energy Market of the Southern African Power Pool as presented to the 2004 General Meeting.

P Naidoo[1], Member IEEE, L. Musaba[2], Member IEEE, W Balet[3] and A Chikova[4], Member, IEE

Abstract--At the 2004 General Meeting of the Power Engineering Society held in Denver, Colorado, the Southern African Power Pool shared innovative developments in the establishment of a short-term energy market for the members of the Southern African Development Community. With few participating members, the initial trading results were encouraging and impressive.With continued trading to date, an update is provided on results achieved, the challenges and experiences encountered and the plans for enhancement. With technical support from Nordpool, a new spot market platform is under construction. The case of the Southern African Power Pool clearly demonstrates the maturity of the participating countries in sharing and protecting natural resources beyond just the needs and requirements of individual countries. This has a positive contribution to the accelerating impacts from climate change and global warming. The co-operative pool model with competitive trading platforms offers a new arrangement for the electricity supply industry and contributes to lower cost of energy delivered to customers.

Keywords: Cross-Border Trading, Pricing of Electrical Energy, Competitive Markets

I. INTRODUCTION

The trading of electrical energy between neighbouring countries in Southern Africa continues and gathers momentum. The trade mechanisms include bilateral contracts and the short-term energy market. Since commencement of the short term energy market operations, no member has cancelled or withdrawn from the trading portfolio. Further, the trading platform has operated continuously for the last five years and no lost days were recorded. The region has entered the high road growth phase and demand for electrical energy both nationally in each member country and regionally across SADC surges forward.

The proceedings of the 2004 IEEE Power Engineering Society General Meeting held in Denver, Colorado, USA, refers:

The Southern African Power Pool shared innovative developments in the establishment of the short term energy market; essentially a day ahead market operated competitively on the basis of bids and offers from participating operating members of the co-operative power pool [1]. The initial results were promising and encouraging.

This paper recalls the salient features of the competitive market model, checks on the earlier initial conclusions and reports on the results achieved to date.

II. REVIEW OF THE MARKET STRUCTURE OF THE SOUTHERN AFRICAN POWER POOL.

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The Southern African Power Pool (SAPP) is a regional body that was formed in 1995 through a Southern African Development Community (SADC) treaty to optimise the use of available energy resources in the region and supports one another during emergencies. The Co-ordination Centre for the power pool is located in Harare, Zimbabwe. The pool comprises of twelve SADC member countries represented by their respective national power utilities.

Based on intergovernmental agreements, the general arrangement is for the national utilities to engage into long term bilateral contracts for the sourcing and consumption of electrical energy. The intergovernmental agreements and the bilateral contracts form the foundation for cross border electrical energy trading. For the bi-lateral contracts, the pricing of electrical energy is negotiated and the utcome is generally based on the classical economics of supply and demand.

To compliment the bilateral market, it was proposed that a short-term market be established to provide for additional energy trading opportunities. Based on a standard market design approach, the goal was to establish an efficient and robustly competitive wholesale electricity marketplace for the benefit of consumers. This could be done through the development of consistent market mechanisms and efficient price signals for the procurement and reliable transmission of electricity combined with the assurance of fair and open access to the transmission system.

For the design of the Short-Term Energy Market (STEM), the following criteria were submitted as input:

i.) ***Transmission rights*** - Long and short-term bilateral contracts between participants have priority over STEM contracts for transmission on the SAPP interconnectors. All the STEM contracts are subject to the transfer constraints as verified by the SAPP Co-ordination Centre.

ii.) ***Security requirements*** - Participants are required to lodge sufficient security with the Co-ordination Centre before trading commences and separate security is required for each energy contract.

iii.) ***Settlement*** **-** Participants have the full obligation to pay for the energy traded and the associated energy costs. The settlement amounts are based on the invoices and are payable into the Co-ordination Centre's clearing account. It is the responsibility of the Participants (buyers) to ensure that sufficient funds are paid into the clearing account for the Co-ordination Centre to effect payment to the respective Participants (sellers).

iv.) ***Currency of trade*** - The choice of currency is either the United States American Dollar or the South Africa Rand dependent on the agreement between the buyer and the seller.

v.) ***Allocation method*** - The allocation of available quantities based on the available transmission capability is by fair competitive bidding with equal sharing of available quantities to the buyers.

vi.) ***Firm contracts*** - Once contracted, the quantities and the prices are firm and fixed. There are currently three energy contracts that have been promoted in the STEM as follows; monthly, weekly and daily contracts.

In the first pass analysis of trading results and performance, the following conclusions were made and reported [1].

- Excess capacity prevails in the regional market, generally during off peak. Electrical energy prices are generally, on average, lower than that for the bilateral market.

- The number of market participants increased from four in the first year to eight as at May 2003.

- The average tariff of energy traded is in the range from 0.3 to 0.6 USc/kWh. The highest matched price was 1.45USc /kWh.

- The offer prices tend to increase as we approach the cold winter months when the SAPP regional peak demand occurs. This behaviour concurs with the economics of supply and demand.

- Transmission availability determines successfulness of trade. Transmission congestion mainly on the cross border tie lines constrains trade.

III. FEEDBACK REPORT ON PERFORMANCE FROM INCEPTION 2001 TO DATE 2005.

The summary of results for the years 2001 to 2005 (October) is provided in table 1.

TABLE 1: YEARLY TOTALS

Year	Energy Traded GWh	Volume USD Thousands	Average Price US c/kWh
2001	144	595	0.41
2002	739	2,875	0,39
2003	713	3,561	0,5
2004	448	3,332	0,74
2005	234	265	0,11

Table 2 shows the breakdown of the short-term energy market transactions into the daily contracts of bids and offers and that of the post stem bilateral negotiated contracts based on bulletin board posted opportunities.

TABLE 2: YEARLY BREAKDOWN OF STEM MARKET INTO DAILY CONTRACTS AND POST STEM CONTRACTS

Year	Daily Contracts GWh	Post Stem Contracts GWh
2001	143	2
2002	653	86
2003	677	37

2004	433	15
2005	226	8

Tables 3 to 7 provide the monthly totals for each of the Years from 2001 to 2005.

TABLE 3: YEAR 2001 PERFORMANCE: MARKET OPENED IN APRIL.

Month	Energy Traded MWh	Average Price US cents/kWh
April	1,980	0.43
May	19,167	0.38
June	6,902	0.74
July	15,482	0.36
Aug	15,790	0.39
Sept	17,868	0.47
Oct	18,055	0.48
Nov	13,570	0.30
Dec	35,379	0.38
Total	144,193	0.41

TABLE 4: YEAR 2002 PERFORMANCE

Month	Energy Traded MWh	Average Price US cents/kWh
January	44,224	0,41
February	29,295	0,50
March	28,727	0.48
April	42,635	0.39
May	47,073	0.43
June	67,783	0.35
July	120,929	0.31

August	90,983	0.33
September	75,295	0.36
October	79,734	0.36
November	48,530	0.37
December	63,371	0.60
Total	738,579	0.39

TABLE 5: YEAR 2003 PERFORMANCE

Month	Energy Traded MWh	Average Price US cents/kWh
January	71,643	0.40
February	72,007	0.44
March	62,858	0.43
April	64,133	0.44
May	66,740	0.62
June	63,231	0.45
July	60,128	0.62
August	56,714	0.59
September	42,990	0.49
October	40,576	0.49
November	51,885	0.52
December	60,437	0.53
Total	713,342	0.50

TABLE 6: YEAR 2004 PERFORMANCE

Month	Energy Traded MWh	Average Price US cents/kWh
January	25,243	0.50

February	20,089	0.71
March	54,693	0.65
April	64,808	0.96
May	61,236	0.70
June	20,670	0.87
July	18,809	0.92
August	22,657	0.53
September	28,299	0.76
October	22,289	0.64
November	57,291	0.83
December	52,272	0.67
Total	448,356	0.74

And finally the first ten-month results for 2005 are provided in Table 7.

TABLE 7: FIRST TEN-MONTH RESULT FOR 2005

Month	Energy Traded MWh	Average Price US cents/kWh
January	45,079	0,100
February	43,283	0,126
March	55,215	0,115
April	45,495	0,129
May	20,068	0,098
June	15,339	0,086
July	9,226	0,117
August	10,000	0,144
September	11,000	0,128
October	15,400	0,133
Total	233,705	0,113

Southern Africa, biased on the dominant South Africa, continues to deliver the worlds lowest cost electrical energy. From the 2005 Annual Report for Eskom South Africa [2], we record the following trend in world industrial electricity prices as presented in Table 8.

TABLE 8: WORLD INDUSTRIAL ELECTRICITY PRICES [2]

Price Range in US	Country

cents / kWh	
2 to 4	South Africa
4 to 6	Canada, Australia, Sweden and Finland
6 to 8	France, UK, USA, Spain
8 to 10	Netherlands, Denmark, Belgium, Germany
10 to 12	Italy

The challenge for South and Southern Africa is to continue to jealously guard the global competitive edge in terms of worlds lowest cost of electrical energy whilst simultaneously promoting new generation and transmission capital expenditures and higher margins of business profitability. These requirements are in tension and new innovative and creative lower cost engineering solutions are necessary. The economic challenge is transferred to the engineers.

IV. ANALYSIS OF RESULTS

The initial conclusions as presented to the 2004 General Meeting continue to be valid. In addition, we can add the following observations:

- The marginal cost of electricity for the Southern African region is in the order of 0,5 US cents/ kWh. The low marginal cost indicates very low primary fuel input costs. This primary energy base of principally coal and hydro requires further work in promoting environmentally friendly designs such as clean coal combustion and run of river hydro generation. The Westcor project and additional base load thermal generation in South Africa and Botswana will enhance volumes whilst sustaining Southern Africa's lowest cost competitive position amongst world industrial production.

- The reduction in energy traded during the winter of 2004 and 2005 is indicative of a reduction in supply offers as compared to sustained heavy demand for bids. In June 2004, a total of 62, 945 MWh was on supply offer as compared to a demand of 338,316 MWh. Similar trends are reported for 2005; in May the supply offer dropped to 49,742 MWh against a demand bid of 321,867; in June the figures were 34,812 MWh versus 307,903 MWh and in July we had 15,837 MWh versus 309,762 MWh. In general supply offers lags demand bids and in the general case, any new generator coming on stream right now has a ready made market; admittedly at the world's lowest marginal costs of around 0,5 US cents/ kWh.

- An interesting result is the further reduction in the average price even when supply offers were greatly reduced. The best guess explanation is that market depression promoted reduced interest and hence lower level of participation and effectively no competition. Thus the lowest bid secured the supply on offer.

V. CONCLUSION

Given the increased supply constraint emanating from the surging demand due to economic growth; the existing transmission congestion and the limited number of operating members, the market continues to sustain and operate as designed. The results are encouraging and is certainly a global leader in terms of cross border energy trading. From inception to date, the market managed to achieve USD 12,28m in volume trade. For an emerging market such as the Southern African Development Community, the result demonstrates confidence and further supports new investments.

In academic terms, the integrated market model of bilateral contracts complemented by competitive bid and offers has value. Each member of the co-operative power pool continues as a monopoly entity within the national borders and this has no relevance when bids and offers are competitively priced in cross border transactions. In the final open market model nationally and regionally, it could be argued that the market participant behaviours would continue to be similar to that of present members but market liquidity would increase.

Market liquidity will promote new energy storage and new quick start and quick stop generation investments together with the preferred environmentally friendly renewable options. Energy storage or energy banking which has the time value attribute is a highly recommended proposal that requires further study and investigation.

It is known that the regional load profile has valleys and peaks and that the Great Lakes of Central Africa have a potential natural height that could be further explored for energy storage and energy banking opportunities.

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VII. BIOGRAPHIES

Pat Naidoo is the Senior General Manager for Eskom in South Africa. He is a Member of the IEEE, the SAIEE and a registered professional engineer.

Lawrence Musaba is the Co-ordination Centre Manager for the Southern African Power Pool. He is an IEE Member and Chartered Engineer.

William Balet is the past Executive Director of the New York Power Pool and currently the USAID Senior Advisor to SAPP.

Alison Chikova is the Senior Engineer at SAPP in charge of Power System Studies. He is an IEE Member and Chartered Engineer

10. The Western Power Corridor Project-- Status and Feedback Report

P Naidoo1#, ***Member IEEE***

Abstract—At the 2005 General Meeting of the Power Engineering Society held in San Francisco, California, the Southern African Power Pool and NEPAD flagship project, the Western Power Corridor, was presented. This paper updates the project diary of events, presents the next steps for the pre-feasibility studies and records the closure of the first pass planning studies to yield the proposal of extra high voltage DC transmission coupled with run of the river hydro generation.

Keywords**:** Feasibility Studies, HVDC Transmission, Hydro Generation Introduction

I. NOMENCLATURE

SNEL: Societe Nationale d' Electricite
ENE: Empresa Nacional De Electricidade
SAPP: Southern African Power Pool

II. INTRODUCTION

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.

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.

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.

In addition, ENE of Angola has submitted 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.

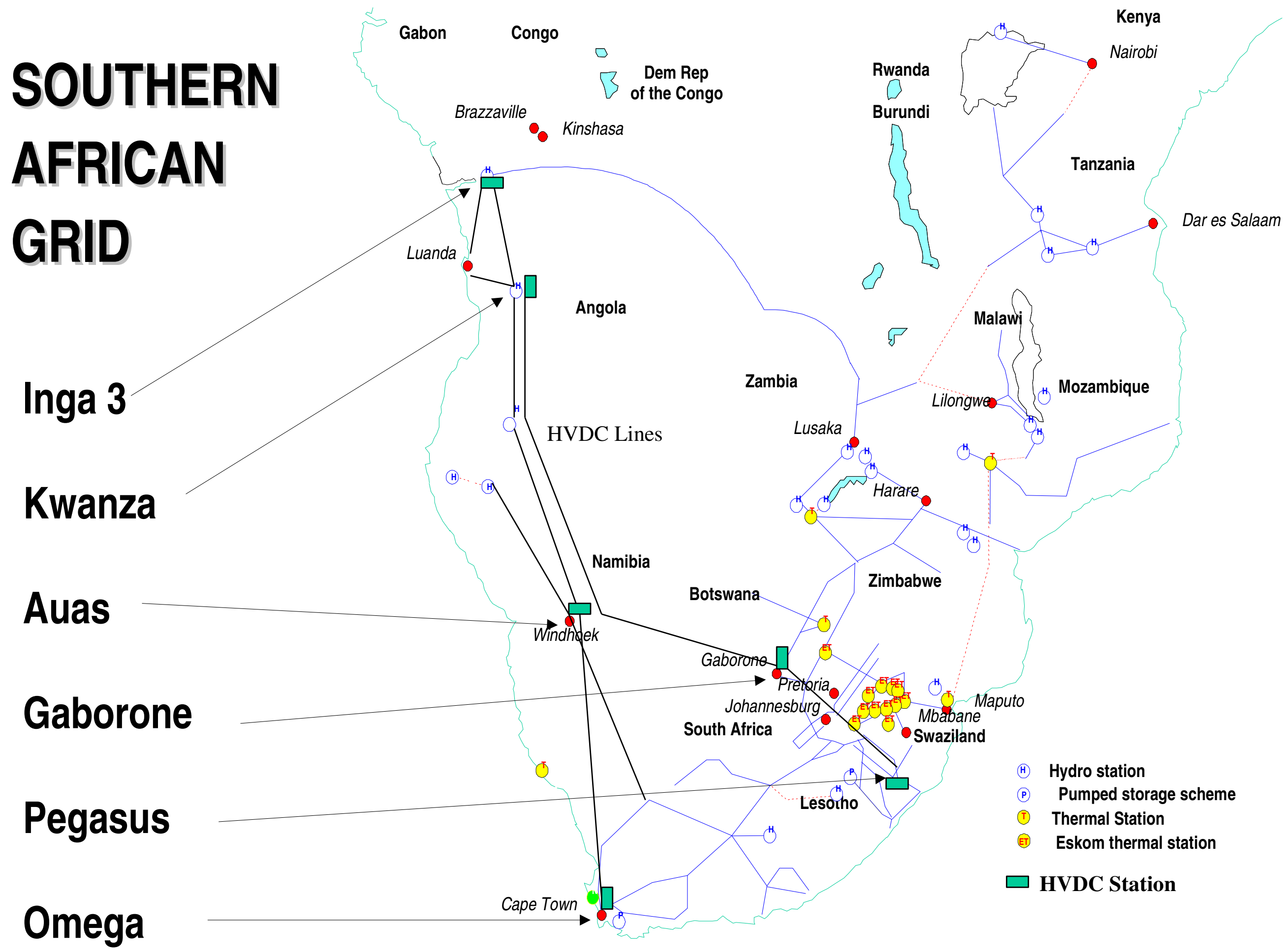

Figure 1: The Western Corridor Power System Interconnecting with the Southern African Power Pool Regional Grid

The paper presented provides the status and report back on the project progress, the details of the scope of work for the pre feasibility studies, the feasibility studies and the steps towards project financial closure. 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].

III. DIARY OF EVENTS

April 24, 2002: Hilton Hotel, Durban, South Africa
The 11th Southern African Power Pool Executive Committee Meeting

To support the growing trade between the Southern African countries, the Southern African Power Pool launched the establishment of the Western Power Corridor.

March 4-8, 2004
Westcor Technical Workshop

High Voltage Direct Current Engineering
Johannesburg, South Africa

International manufacturers of electrical power equipment review the project intent and conclude that the project is doable in terms of moving bulk power over the long distances. The technology will involve high voltage direct current transmission at voltages of 800 kV together with run of the river hydroelectric power generation.

October 22, 2004
Energy Ministers Forum
Chief Executive Steering Committee Meeting
Pretoria, South Africa

The Energy Ministers of South Africa, Botswana, Namibia, Angola and the Democratic Republic of Congo approve the inter-governmental memorandum of understanding [IGMOU] for the establishment of the WESTCOR Joint Venture Company, with a project office to be based in Gaborone, Botswana. At the same meeting, the Chief Executives of the five participating utilities viz. Eskom Holdings Limited of South Africa, Botswana Power Corporation of Botswana, Nampower of Namibia, ENE of Angola and SNEL of the DRC signed the Inter-Utility Memorandum of Understanding [IUMOU] to pave the way for the establishment of the WESTCOR joint venture company comprised of generation, transmission and broadband telecommunications for power system operations and control.

November 10,2004
Chief Executive Steering Committee Meeting
Presentation of the First Pass Study Results and Project Timetable
Johannesburg, South Africa

The recommendations of the working group that was submitted and approved included:

- The establishment of a project office in Botswana, Gaborone
- The process for the appointment of the Project Manager
- The planned 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.
- The planned 500 kV HVAC integration of the Angolan and DRC National Grids
- The planned two 500 kV HVDC transmission schemes; one circuit having a 2 GW rectifier at Inga (DRC), 1,5 GW inverter at Omega (South Africa) and 500 MW tap at Auas (Namibia) and the second circuit having a 2 GW rectifier at Kwanza (Angola), 1,5 GW inverter at Pegasus (South Africa) and a 500 MW tap at Gaborone (Botswana).
- The proposal to investigate extra high voltage direct current transmission (800 kV) for higher load transfers over longer distances for future load growth options.
- The timetable for pre-feasibility and feasibility studies at an approximate cost of $7,5 to $8m USD.

April 24,25,2005
Satellite Applications Center
Johannesburg, South Africa

First pass servitude route selection using satellite technology.

SADC Heads of State Council Meeting
14 August 2005, Gaborone, Botswana
Southern African Power Pool

WESTCOR is a SADC project conceived through the combined initiative of the SADC Secretariat and the power utilities of Angola, Botswana, DRC, Namibia and South Africa. The project's aim is to harness the large water resources of the Congo River at Inga, to produce and supply electric power, initially for the five countries involved but ultimately to the whole SADC sub-region. The project will comprise the construction of a 3,500 MW hydroelectric dam, a transmission line and a telecommunications line. The project is estimated to cost about US$ 7.0 billion and the funding is expected to be sourced through New Partnership for Africa's Development (NEPAD) and other ICP's. The Feasibility studies are expected to cost approximately US$ 8 million.

Signing of Shareholders Agreement
September 7,2005 Gaborone, Botswana

The Westcor Joint Venture Company, Westcor (PTY) LTD was formally registered and launched in Gaborone, Botswana on the 7 of September 2005. The present day effort is to appoint a Chief Operating Officer, to populate the Board of Directors and to launch the feasibility studies. Five utilities are participating in the project, namely, SNEL (DRC), ENE (Angola), Nampower (Namibia), BPC (Botswana), and Eskom (South Africa). Each utility owns 20% of the share capital and has deposited the first owners' equity funds into the company bank account. Together with commercial debt and development funding, the US$8m feasibility studies is scheduled for completion by 2007.

IV. THE SCOPE OF WORK FOR THE FEASIBILITY STUDIES

The planned scope of works for the pre-feasibility studies will commence with the environmental impact assessment. Other elements of this portfolio includes:

- Transmission line route and servitude selection and options
- Transmission line survey mapping and line profiling
- Initial civil and electrical designs for the Inga 3 run of river power station
- HVAC and HVDC line designs
- Substation and converter station layouts
- Project Management Strategies
- Power purchase agreements
- Least cost financial and economic life cycle analysis
- First pass business plan

The feasibility scope of works would include the following:

- Detailed engineering designs, drawings and bill of quantities
- Expert review and critical evaluation
- Technology and Engineering Risk Analysis
- Management strategies for operating and maintenance
- Funding options
- Project Closure for capital financing
- Project Management Contracting
- Procurement Tenders
- Commissioning Timetable

This whole portfolio of work would be launched by the Chief Operating Officer of Westcor and managed by the Board of Directors. This step also signals the closure of the first pass project planning and proposal.

V. FIRST INPUT FOR TRANSMISSION LINE DESIGN

The feedback from the satellite applications workshop shows that multiple DC circuits would need to be packaged into the least number of servitudes. The Western region of Southern 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 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.

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.

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

- The design must make no allowance for servitude maintenance such as cutting and clearing of natural vegetation such as trees and shrubs;
- 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 kept to an absolute minimum 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 energised air gaps

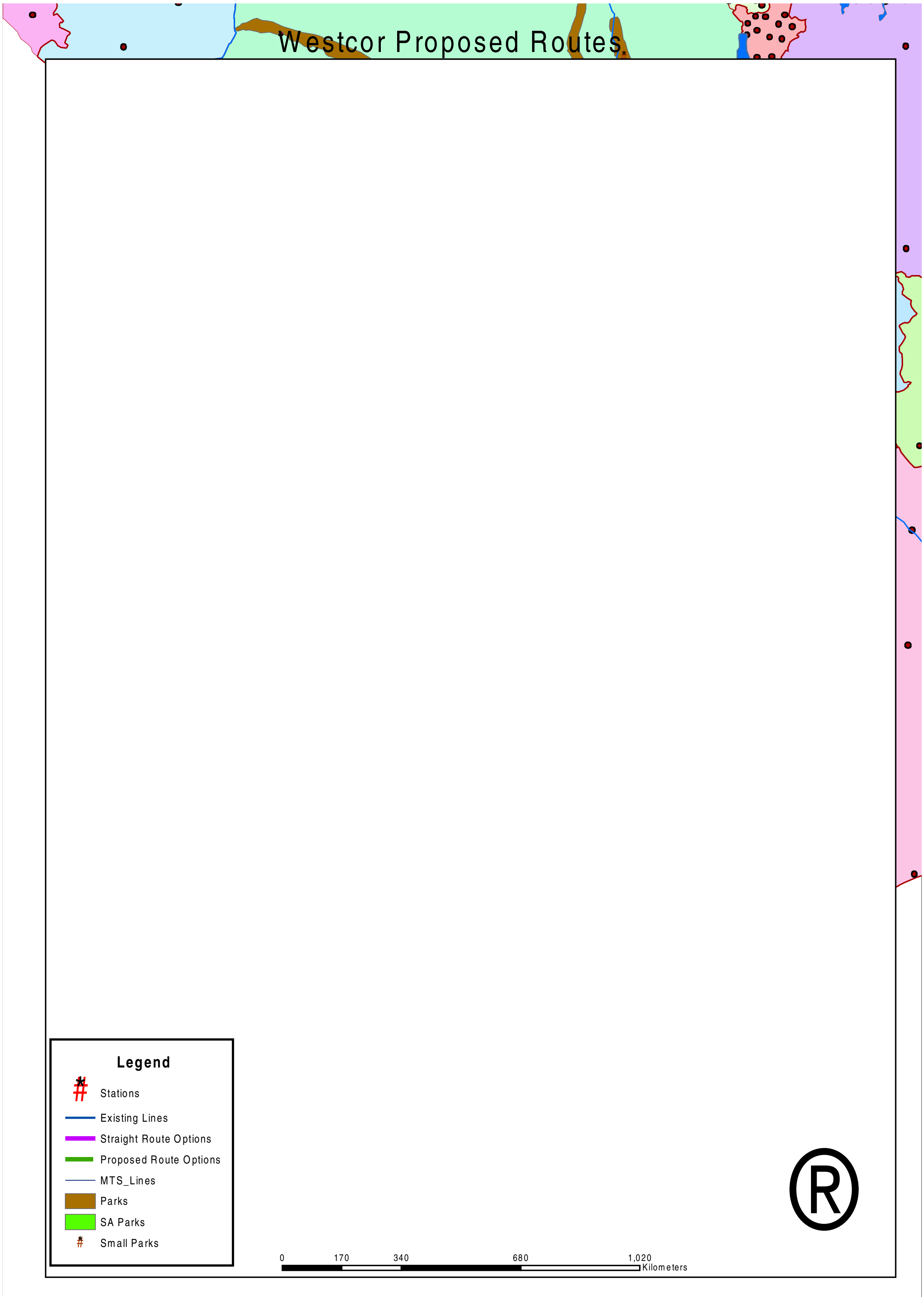

Figure 2: Optional Routes for Transmission Line Servitudes.

An artist impression of a composite bipole line design is shown in Figure 3. 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

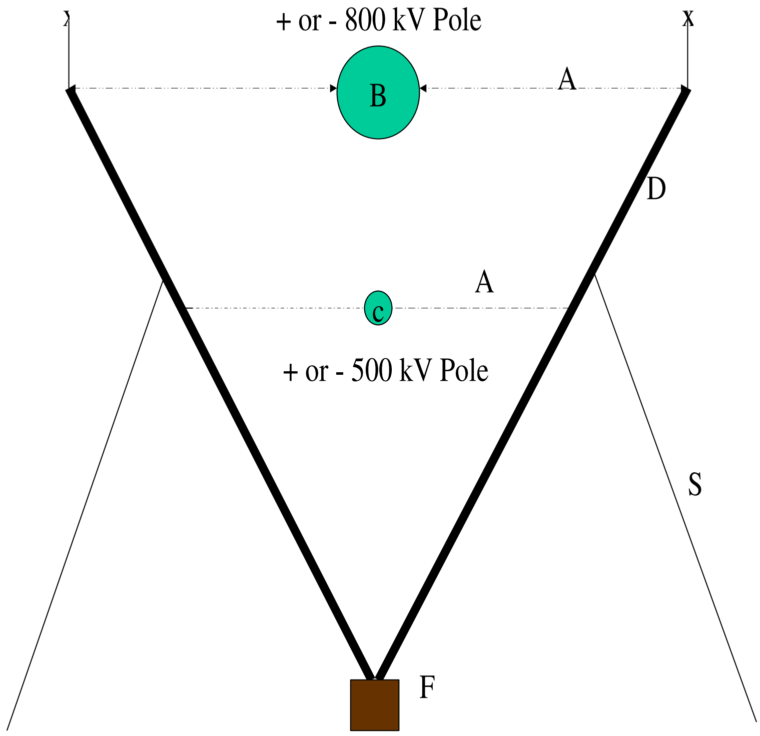

Figure 3: An artist impression of a composite 500 kV and 800 kV positive or negative polarity pole as a guyed structure.

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.

VI. 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 project 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 primary energy. 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. The ideas presented would be further explored during the pre-feasibility phase of the project engineering.

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IX. ACKNOWLEDGEMENT

The Western Power Corridor project has been prepared by a joint working group of the five participating utilities of the five countries. This report is an output emanating from the activities of the working group and is presented by the author for and on behalf of the working group in his capacity as the Chairman of the Technical subcommittee and a member of the Joint Working Group.

11. Update on the Gulf Cooperation Council (GCC) Electricity Grid System Interconnection

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Abstract – This paper describes the development of the interconnection between the Gulf States (Kuwait, Saudi Arabia, Bahrain, Qatar, UAE and Oman). 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. This paper also describes the principal components of the interconnection as well as some of issues, which had to be addressed such as creation of the GCC Interconnection Authority, cost sharing and financing before the project could proceed towards implementation.

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

I. INTRODUCTION

Recognizing the benefits of interconnection of their power grids, the six Arab states of Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates (UAE) and Oman a study was carried out in 1990 to define an Interconnection Project and to determine its feasibility. The study recommended 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.

As recommended in the 1990 study, the Gulf Co-operation Council Interconnection Authority (GCCIA) has been established and given the mandate to proceed towards implementation of the Interconnection Project.

It was decided in 2002 to update the studies that had been carried out and to re-confirm the feasibility of the Interconnection Project, carry out a Market study, prepare a plan for financing of the Project, develop the Agreements that have to be reached between the different countries, and prepare an implementation strategy.

In 2004 it was decided to finance the Project with funds from the member countries. Once the decision was made on the financing it was decided to proceed to produce the Tender documents in different work packages as set out in the implementation strategy.

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.

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II. EVOLUTION OF THE POWER SECTORS IN THE GCC COUNTRIES

In 1990 all the power utilities were government owned and vertically integrated. Governments in the region have already embraced the need and accepted the benefits of private sector participation in the power sector. Since then, legislation has been passed in Oman, U.A.E., Qatar and Saudi Arabia allowing the construction and operation of private power (and desalination) plants. Most of the GCC countries are also in the process of unbundling their power sector into separate generation, transmission and distribution entities. In Saudi Arabia, the electricity companies have been consolidated into one Saudi Electricity Company (SEC) with plans to introduce functional separation of generation, transmission and distribution. Bahrain has allowed private sector participation in generation. In Qatar, functional separation of generation, and transmission and distribution has been allowed along with private sector participation. Abu-Dhabi, one of the Emirates in UAE, has already implemented functional separation, and separate generation, transmission and distribution companies exist. In Oman the operational responsibility for the electricity sector has been transferred from the Ministry to newly created generation, transmission and distribution companies. Currently Kuwait has no plans for restructuring and the power sector is likely to remain vertically integrated.

The presence of an Interconnection between the GCC countries will in addition to enabling sharing of reserves, thus reducing the generation requirements in each country, provide the opportunity for trading electricity between the member countries as well as eventually trading outside the GCC.

III. DEMAND GROWTH IN THE GCC COUNTRIES

The demand in the GCC countries as shown in the Table 1 is expected to grow from 32,747 MW to almost 94,000 MW over the next 25 years.

TABLE 1. DEMAND GROWTH UP TO 2028

Country	Year (MW)			
	2003	2008	2010	2028
Kuwait	7685	10284	11555	27017
Saudi Arabia*	9910	13945	14745	23310
Bahrain	1547	2070	2325	4989
Qatar	2308	3184	3387	4649
UAE	9137	12780	14383	29358
Oman	2160	2662	2824	4558
Total:	32747	44925	49219	93781

* The Saudi Arabia demand only includes the demand supplied by the SEC-ERB (i.e. the load in the Eastern Region and the firm exports to the Central Region)

IV. THE INTERCONNECTION PROJECT

The studies recommended that the grid system interconnection between the GCC states be carried out in three phases as shown diagrammatically in Figure 1.

FIGURE 1. APPROXIMATE ROUTE AND LAYOUT OF THE GCC INTERCONNECTION

- Phase I: Interconnection of the Northern Systems (Kuwait, Saudi Arabia, Bahrain and Qatar) in 2008.
- Phase II: The internal interconnection of the Southern Systems (UAE and Oman) to form the UAE National Grid and the Oman Northern Grid.
- Phase III: Interconnection of the Northern and Southern Systems in 2010.

The capacity of the Interconnection to each of the countries is given in Table 2:

TABLE 2. SIZE OF INTERCONNECTION TO EACH GCC STATE

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

V. BENEFITS OF THE INTERCONNECTION PROJECT

The principal benefits that can be achieved through Interconnection are as follows:

- Interconnections result in the requirement for a lower installed capacity in each of the systems (due to reserve sharing) while still supplying the load with the same (or better) level of reliability.
- Interconnections can permit larger and more efficient generating units to be installed on the individual systems.
- Interconnections enable systems to share operating (spinning) reserves so that each system can carry less spinning reserve.
- Interconnections enable interchange of energy between systems resulting in a lowering of total operating costs.
- Interconnections permit assistance from neighboring systems to cope with unforeseen construction delays and unexpected load growth.
- Interconnections permit emergency assistance between systems to mitigate the effects of unforeseen contingencies such as catastrophic multiple outages.
- Interconnections permit exchange of power between the interconnected systems

The principal benefits due to the interconnection arise from the sharing of reserves between the systems and the consequential reduction in the installed generating capacity and associated operating and maintenance costs in the GCC countries. This was used to justify the Project. However, there is a large potential of exchange of economy energy between the systems, given the availability of gas for power generation in some of the systems and crude oil in the others.

VI. BASIC ELEMENTS OF INTERCONNECTION PROJECT

The Interconnection Project consists of the following principal elements:

Phase I

- 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 III

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

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

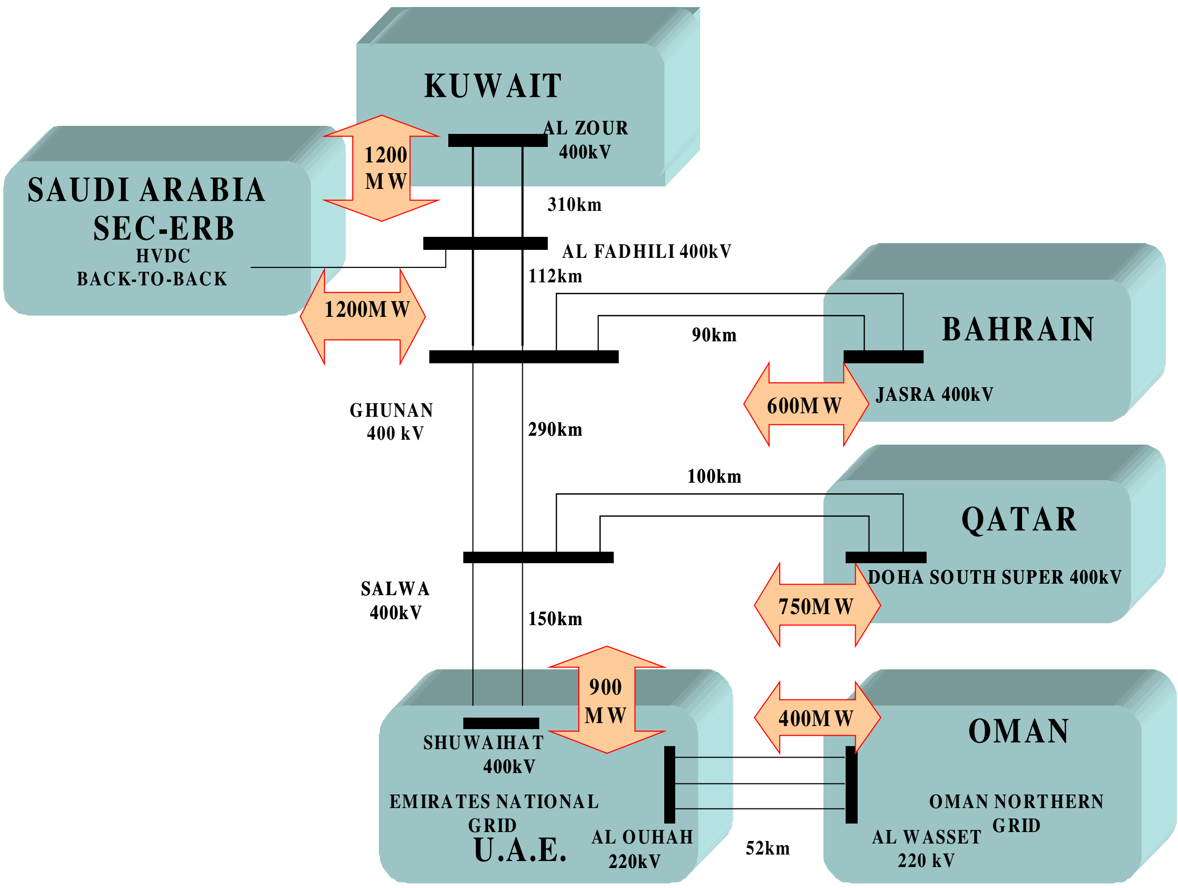

FIGURE 2. CONCEPTUAL DIAGRAM OF THE INTERCONNECTION SYSTEM

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

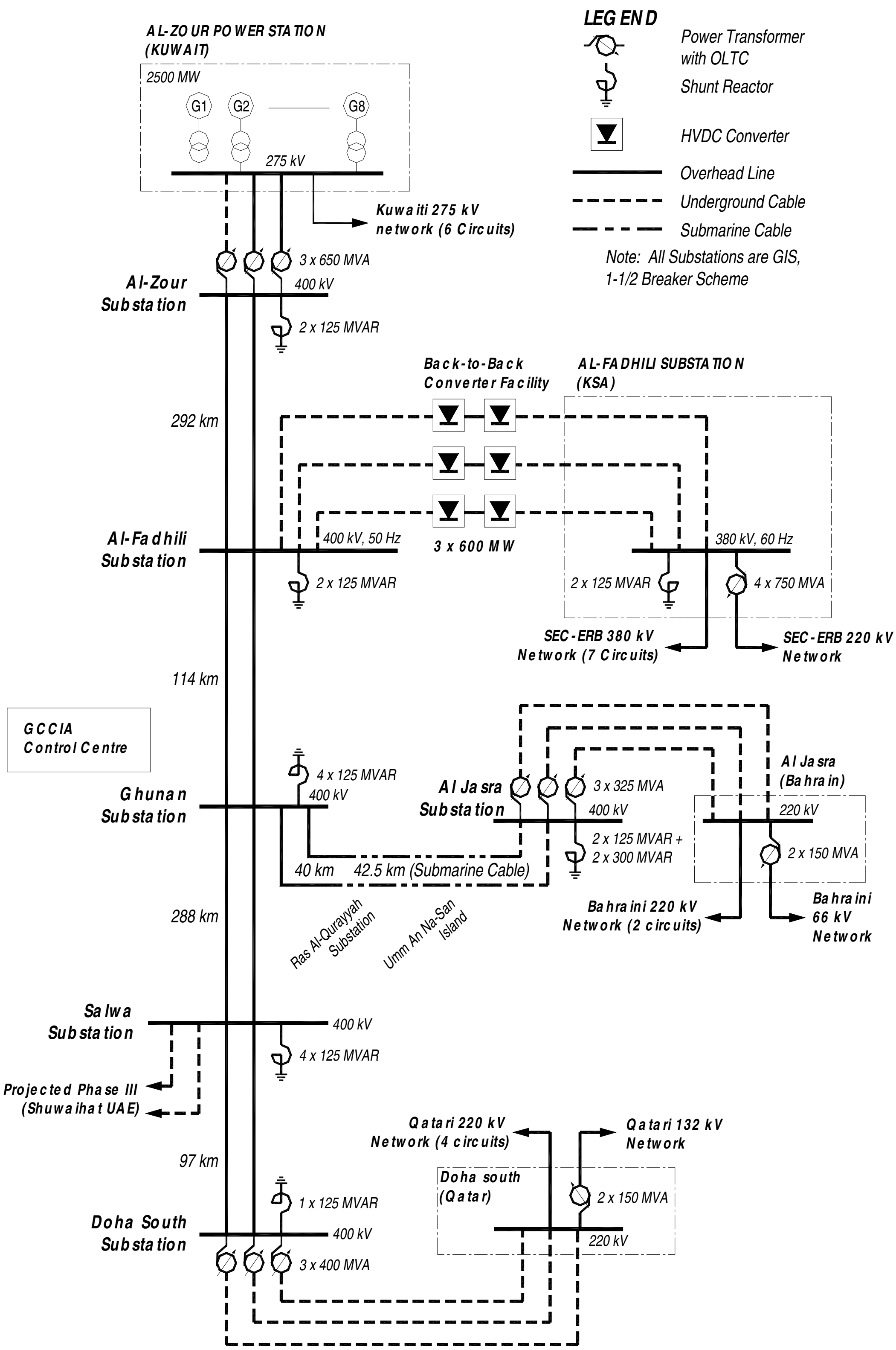

FIGURE 3. SIMPLIFIED SINGLE-LINE DIAGRAM OF THE INTERCONNECTION

VII. DESCRIPTION OF THE PRINCIPAL COMPONENTS

The GCCIA Project (Phase I) will comprise the following principal components:

- Six GIS Substations;
- 830 km of 400 kV Transmission Lines;
- 400 kV Submarine Cables;
- 3 x 600 MW HVDC Back-to-back Frequency Converter Facility;
- Control, Protection & SCADA and Telecommunication Systems.

Descriptions of some of the components of the Interconnection Project are 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

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.

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 Shuwaihat (UAE) in Phase III of GCCIA interconnection project in the future.

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

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. 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 292 km (about 62 km are in Kuwait).

From Al Fadhili, the overhead transmission line will depart southward to Ghunan a distance of 114 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 288 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 Area 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 40 km, where it will connect to the submarine cables to Bahrain.

C. 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 SF6 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 (40) km of submarine cables (armoured) and approximately eight (8) 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.

D. 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.

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.

VIII. COSTS OF THE INTERCONNECTION PROJECT

The cost of the Interconnection Project based on the Tenders received in 2005 for Phase I is $US 1095 million.

IX. SHARING OF THE COSTS OF THE INTERCONNECTION PROJECT

It was agreed amongst the countries to share the costs of the Interconnection in proportion to the reserve capacity savings. Considering the time value of money and that the capacity savings occur at different points of time, it was agreed to share the costs in proportion to the present value of the capacity savings.

The agreed sharing of the costs of the Project are as given in Table 3.

TABLE 3. COST SHARING

Country	Phase I	Phase I & III
Kuwait	33.8%	26.7%
Saudi Arabia	40.0%	31.6%
Bahrain	11.4%	9.0%
Qatar	14.8%	11.7%
UAE	---	15.4%
Oman	---	5.6%
Total	100.0%	100.0%

X. FINANCING FOR THE PROJECT

Various options of financing the total cost (capital and operational) of the project were considered.

The GCCIA was set up such that the member countries would have 100% ownership and would be responsible for all the financing risks. Each country is responsible for its designated share of the investment in the Project and will be responsible to provide 35% equity and to guarantee the remaining 65% provided from loans.

XI. 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 December 2008.

XII. 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.

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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 of Power Systems in the Energy 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 Electrical Engineers (Fellow).

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