IEEE POWER ENGINEERING SOCIETY
ENERGY DEVELOPMENT AND POWER GENERATION COMMITTEE

PANEL SESSION: STATUS OF INTERNATIONAL INTERCONNECTIONS AND ELECTRICITY DEREGULATION IN AFRICA

IEEE 2004 General Meeting, Denver, USA, June 2004

TOWARDS DEVELOPING A COMPETITIVE MARKET FOR REGIONAL ELECTRICITY CROSS BORDER TRADING: THE CASE OF THE SOUTHERN AFRICAN POWER POOL.

SAPP Competitive Electricity Markets Working Group

Mr. P Naidoo, Dr. L. Musaba, Mr. W Balet and Mr. A Chikova
SAPP Coordination Centre, 17th Floor Intermarket Life Tower, 77 Jason Moyo Avenue,
PO Box GT897, Harare, Zimbabwe
sapp@africaonline.co.zw

Unpublished, Updated and Released 5 December 2003

Abstract

Regional electricity cross border trading is governed by fixed co-operative bilateral agreements, generally of a long-term duration. The fixed power purchase agreements provide for the assurance of security of supply but are not flexible to accommodate varying demand profiles and varying prices. The pricing of electrical energy defers for periods of peak and off peak consumption. To explore further the benefits thereof, the sourcing and scheduling of electrical energy closer to the time of dispatch was investigated. Research has shown that competitive bidding is one option for sourcing and securing supplies closer to real time dispatch. Using the experiences of the Southern African Power Pool (SAPP) as a case study, a competitive market framework for cross border electrical energy trading was developed. In April 2001, the market commenced trading with a few participants. With increasing participants and market confidence, the results of the first two years show that the model is robust and is a recommended framework for cross border short term electrical energy trading. The short-term energy market (STEM); designed to be day-ahead, compliments the bilateral market and provides another technique for the pricing of electrical energy. With the addition of real time communications and energy management systems, the spot market for competitive bidding is the next step.

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

---

1. Introduction

The trading of electrical energy between neighbouring countries is synonymous with economic development and the enhancement of the quality of societal life. 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. The routine activities that follow include scheduling, settlements and the monitoring of quality of supply. Further on, based on events, detailed investigations are conducted into inadvertent energy flows and major power system faults and disturbances.

For the bi-lateral contracts, the pricing of electrical energy is negotiated and the outcome is generally based on the classical economics of supply and demand. At times of peak consumption, the price for electrical energy is generally higher. At times of off-peak consumption, the prices are generally lower. Comparison of the difference in rates for peak and off-peak consumption for four countries in the Southern Africa market is given in Table-1.

The off-peak tariff in most countries is approximately 40% of the peak tariff. This difference promotes new business opportunities. Hence, we introduce a new process for pricing of electrical energy in the short term.

Table-1: *Difference in Rates for Peak and Off-Peak consumption for domestic customers with a monthly average consumption of 450 kWh in four countries in the Southern African Electrical Energy Market.*

Country	Peak to Off-Peak Differences in rates
South Africa	Peak: 0.034 US$/kWh Off-Peak: 0.014 US$/kWh Difference: 0.020 US$/kWh
Zimbabwe	Peak: 0.051 US$/kWh Off-Peak 0.020 US$/kWh Difference: 0.031 US$/kWh
Botswana	Peak: 0.040 US$/kWh Off-Peak: 0.016 US$/kWh Difference: 0.024 US$/kWh
Namibia	Peak: 0.033 US$/kWh Off-Peak: 0.013 US$/kWh Difference: 0.020 US$/kWh

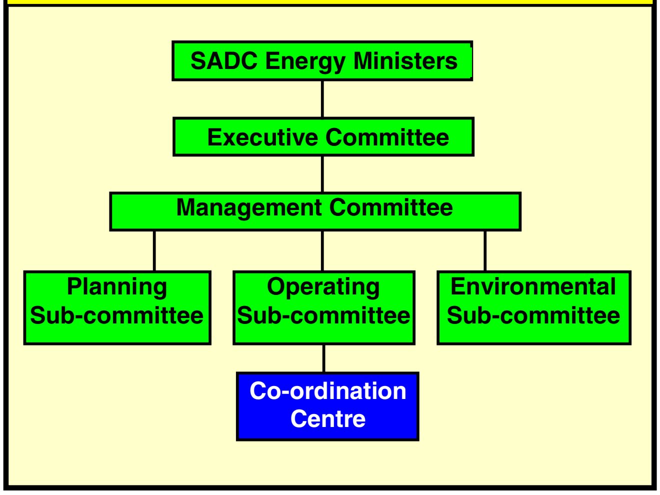
The time-based differentiation in pricing arises from the physical constraint in that the produced electrical energy must be instantly consumed. The storage of electrical energy is not practical. Energy banking and pumped storage schemes are the exceptions for electrical energy storage for a very small percentage of the total electricity generated.

2. Case Study for the Southern African Power Pool

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 support 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.

SAPP is managed by the decision-making that occurs in the hierarchical structured committees illustrated in Figure-1. Reporting to the Energy Ministers of SADC is the Executive Committee that is composed of the Chief Executives of the participating utilities. Reporting to the Executive Committee is the Management Committee, which is composed of senior managers from the transmission system operations and energy trading divisions of each utility.

Figure 1. : SAPP structure



The Management Committee collates the proceedings of the sub-committees of Operating, Planning and Environmental, summarizes the proposals and recommendations and presents bi-annually the report to the Executive Committee. In the SAPP proceedings of 1999, the recommendation from the Operating Sub-Committee to introduce a competitive market for short-term energy trading was submitted and approved. This paper will discuss in depth the design and rules of the short-term energy market. The results of more than two years of trading activity will be analysed for recommended conclusions.

3. Design of the Short Term Energy Market

The goal of standard market design is to establish an efficient and robustly competitive wholesale electricity marketplace for the benefit of consumers [1]. 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.

To commence the design process, three working groups were tasked to detail the parameters for settlements (Treasury Working Group), the parameters for trading (Trading Working Group) and the parameters of governance (Legal Working Group). The working groups were composed of specialists from the participating utilities. The work was conducted over a period of one year.

The results of the working group is summarized and given in Table-2.

Table 2: *Summary of Design Features for the Short Term Energy Market.*

Working Group	Tasked Activities
Treasury Working Group	• Currency of trade. • Security of Payments • Clearing Institution & location • Settlement process
Trading Working Group	• Trading Platform • Wheeling Charges • Trading Rules • Daily Scheduling Procedures • Market Structure
Legal Working Group	• Governance documents • Regulatory Rules • Agreements

The trading platform for the new competitive short-term market was designed locally. The platform employs a matrix for the solution of simultaneous linear equations that were formulated as follows.

Assume that ***P*** *MW* of power is on offer and that there are altogether ***n*** offers and ***m*** bids. Let us also assume that a given bidder ***j*** receives power from a given seller ***i*** and that this power is P_{ij} as illustrated in Table-3.

For ***n*** offers, it can be shown that

$$\left.\begin{aligned} &P_{11}+P_{12}+P_{13}+P_{14}+\ldots+P_{1m}=\sum_{j=1}^{m}P_{1j} \\ &P_{21}+P_{22}+P_{23}+P_{24}+\ldots+P_{2m}=\sum_{j=1}^{m}P_{2j} \\ &. \\ &. \\ &. \\ &P_{n1}+P_{n2}+P_{n3}+P_{n4}+\ldots+P_{nm}=\sum_{j=1}^{m}P_{nj} \end{aligned}\right\} \qquad (1.0)$$

Table-3
Power Allocation Table

		1	2	3	4	
		BIDS				
	OFFERS	*NAM*	*SEB*	*LEC*	*ZESA*	*TOTAL*
1	*SNEL*	P_{11}	P_{12}	P_{13}	P_{14}	$\sum_{1}^{4}P_{1j}$
2	*ZESCO*	P_{21}	P_{22}	P_{23}	P_{24}	$\sum_{1}^{4}P_{2j}$
3	*EDM*	P_{31}	P_{32}	P_{33}	P_{34}	$\sum_{1}^{4}P_{3j}$
4	*ESKOM*	P_{41}	P_{42}	P_{43}	P_{44}	$\sum_{1}^{4}P_{4j}$
	TOTAL	$\sum_{1}^{4}P_{i1}$	$\sum_{1}^{4}P_{i2}$	$\sum_{1}^{4}P_{i3}$	$\sum_{1}^{4}P_{i4}$	$\sum_{1}^{4}P_{ij}$

Similarly for ***m*** *bids* we get,

$$\left.\begin{array}{l} P_{11}+P_{21}+P_{31}+P_{41}+...+P_{n1}=\sum_{i=1}^{n}P_{i1} \\ P_{12}+P_{22}+P_{32}+P_{42}+...+P_{n2}=\sum_{i=1}^{n}P_{i2} \\ . \\ . \\ . \\ P_{1m}+P_{2m}+P_{3m}+P_{4m}+...+P_{nm}=\sum_{i=1}^{n}P_{im} \end{array}\right\} \quad (2.0)$$

If *OFFER_POWER [i]* is the maximum power offered by ***seller i*** and *BID_POWER [j]* is the maximum power requested by ***bidder j***, then the selling and buying conditions must satisfy the following Equations (3.0) and (4.0) respectively, for offers and bids.

$$\left.\begin{array}{l} \sum_{i=1}^{m}P_{1i} \le OFFER\_POWER\,[1] \\ \sum_{i=1}^{m}P_{2i} \le OFFER\_POWER\,[2] \\ . \\ . \\ . \\ \sum_{i=1}^{m}P_{ni} \le OFFER\_POWER\,[n] \end{array}\right\} \quad (3.0)$$

$$\left.\begin{array}{l} \sum_{j=1}^{n}P_{j1} \le BID\_POWER\,[1] \\ \sum_{j=1}^{n}P_{j2} \le BID\_POWER\,[2] \\ . \\ . \\ . \\ \sum_{j=1}^{n}P_{jm} \le BID\_POWER\,[m] \end{array}\right\} \quad (4.0)$$

The value of the power P_{ij} at other positions can easily be evaluated from the *qualification criterion* as follows. If the offer price from the *seller I* is more than the bidder price by the *bidder j*, then if follows that $P_{ij} = 0$.

It was initially stated that the cheaper power has to be shared first equally amongst all the qualified bidders. Therefore, it follows that the ***cost function*** (i.e. cost per hour) with respect to the bidder must be *minimised* to get the optimal solution for all the offers and bids. The cost function in this case is the product of the price of the offer power by the power allocated to the buyer from the particular seller. The unit of the cost function is therefore *cents per KWh*.

The optimisation problem for any given buyer at position ***j*** and for ***n*** sellers can then be stated as follows:

Minimise:

$$Cost\ f = OFFER\_PRICE[1] * P_{1j} + OFFER\_PRICE[2] * P_{2j} + ... + OFFER\_PRICE[n] * P_{nj}$$

Subject to:

1. $P_{ij} = 0$ for $BID\_PRICE[j] < OFFER\_PRICE\,[i]$
2. Transmission system constraints and other wheeling constraints
3. $\sum_{k=1}^{m} P_{jk} \le OFFER\_POWER\,[j]$
4. $\sum_{i=1}^{n} P_{ij} \le BID\_POWER\,[j]$

There are two ways of solving the optimisation problem of this nature; *Mathematically* using the well-known linear optimisation techniques or simply applying directly the *market rules* that were formulated. The method that was finally adopted combined the two approaches. The market rules simplified the task of incorporating system transmission and wheeling constraints.
The proposed algorithm first allocates the power equally to all the successful bidders. If the power allocated is more than what the bidder requested, adjustments are made to the affected bidder. Then the transmission constraints are applied to check for any system violations. If no violation is detected, the solution is accepted. If violation is encountered, the allocated power is adjusted until no violation is observed.

Using the proposed algorithm a computer program called ***STEM Program Manager*** was written to automate and computerise the allocation of offers to successful bidders.

Example 1

Assume that there are two offers from the two SAPP utilities BPC and EDM respectively and one bid from ZESA as shown in Table-4.

Table-4

Offers and bids for the example

Offers			Bids		
Utility	*Power MW*	*Offer Price US c/kWh*	*Utility*	*Power MW*	*Bid Price USc/kWh*
BPC	100	2.5	ZESA	150	3.0
EDM	100	3.0			

Let

P_1 of power be sold by BPC to ZESA at *2.5 cents per kWh*, and

P_2 of power be sold by EDM to ZESA at 3.0 *cents per kWh* respectively.

The problem can then be stated as that of minimising the bidder *cost function (Cf)* subject to the power requirement constraints as follows:

Minimise: $Cf = 2.5P_1 + 3.0P_2$

Subject to: $P_1 + P_2 \leq 150$

$P_1 \leq 100$, $P_2 \leq 100$,

$P_1 \geq 0$ and $P_2 \geq 0$

The power transfer of P_1 and P_2 to ZESA from BPC and EDM respectively, should not cause any part of the transmission system to be overloaded and should be within utility-to-utility interconnector limits in order to satisfy the transmission system constraints. Note also that in this example there are no wheelers involved.

Table-5 gives a possible combination of P_1 and P_2 that satisfies the cost function under the given constraints.

Table-5

Possible combinations of P_1 *and* P_2

P_1	0	20	40	*50*	*60*	*75*	*80*	*100*	140	150
P_2	150	130	110	*100*	*90*	*75*	*70*	*50*	10	0
$P_1 + P_2$	150	150	150	*150*	*150*	*150*	*150*	*150*	150	150
$Cf = 2.5P_1 + 3.0P_2$	450	440	430	*425*	*420*	*412.5*	*410*	***400***	390	375
	$P_1 + P_2 \leq 150$ Satisfied. $P_2 \leq 100$ **NOT** satisfied. Region NOT Permissible.			$P_1 + P_2 \leq 150$ Satisfied. $P_2 \leq 100$ Satisfied $P_1 \leq 100$ Satisfied. Permissible Region.					$P_1 + P_2 \leq 150$ Satisfied. $P_1 \leq 100$ Is **NOT** satisfied. Region **NOT** permissible.	

It is clear from Table-5 that the minimum cost function is 400 cents per hour and occurs when $P_1 = 100MW$ and $P_2 = 50MW$. Thus ZESA gets 100 MW of power from BPC and 50MW from EDM. If there is more than one bidder, the optimisation procedure given in the example is repeated for each bidder to get the optimum solution.

4. Analysis of Trading Results and Market Performance.

- 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.

- Opportunity for trading short term is available. The highest monthly revenue was equivalent to USD380, 000.00. The figure is projected to increase.

5. Summary of results

5.1. Day ahead market

Figure-2 shows the supply and demand situation for the day-ahead market. At the start of the market, the supply was much higher than the demand, until a year after the market has started was when the demand became higher than the supply.

Figure-3 shows the energy traded together with the associated cost of energy. The energy traded on the STEM market has been increasing on a monthly basis. The main constraint to the trading has been the transfer tie-line limits between the northern and the southern utilities.

5.2 Post STEM Energy Market

The Post STEM energy contracts are concluded outside of the STEM market between participants through bilateral negotiations. Unallocated STEM bids and offers are published on the Internet and these offers and bids are available for hourly trading on the trading day.

This market started in December 2001 and is now about ten percent of the energy traded on the STEM. A higher tariff than the STEM is agreed and trading takes place the next day. The results of this market are shown in Figure-4.

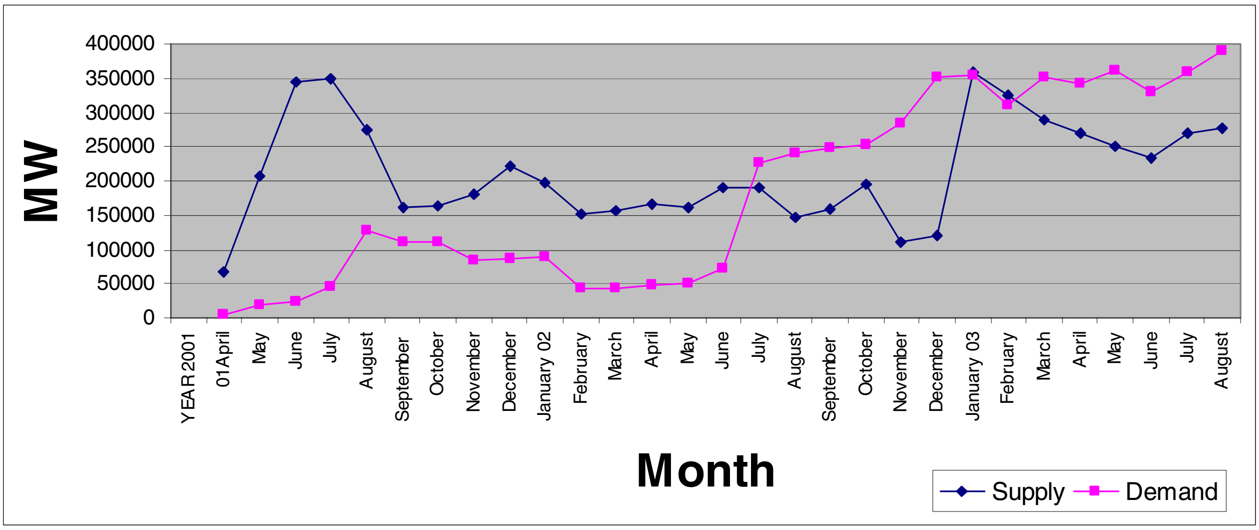


Figure-2: Supply and Demand

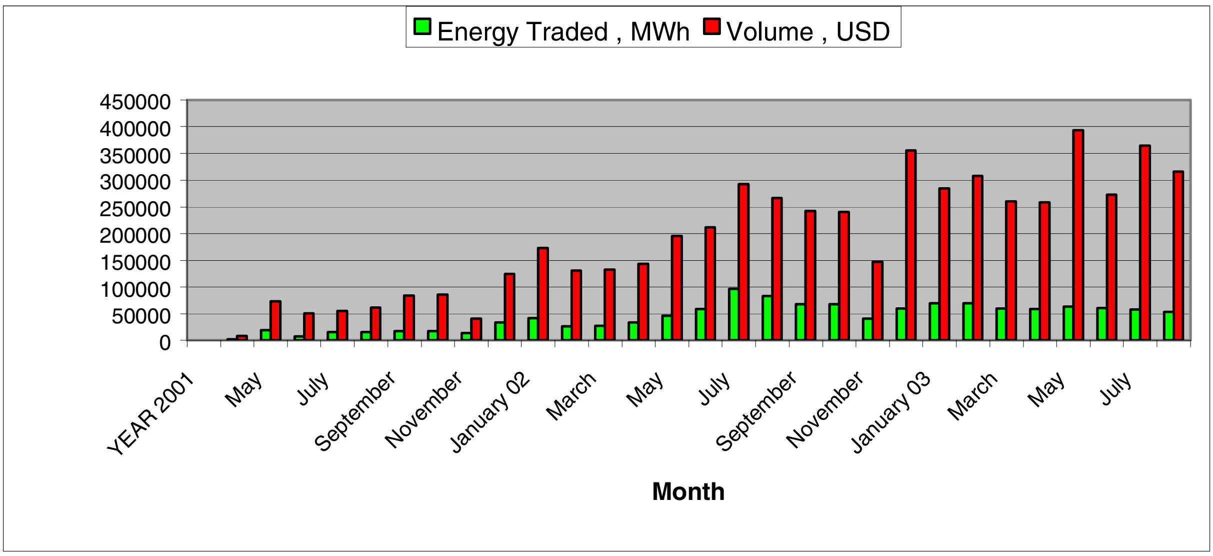


Figure-3: Energy and Volume Traded

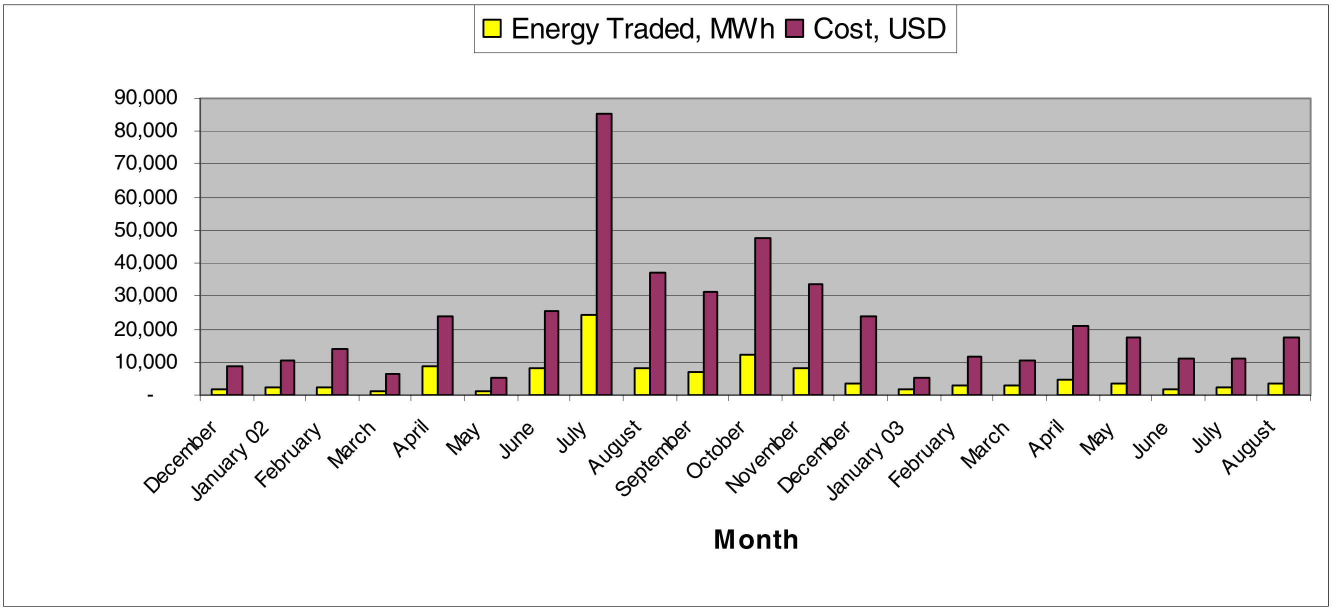


Figure-4: Energy and volume traded in the post STEM energy market

6. Conclusion

At the 1995 Financial Times World Electricity Conference held in London [2], Professor John Chessire of the University of Sussex, noted in his opening address that increasing interdependence of regional economies and with improved transmission technology, cross border trading will emerge and provide new opportunities for cost reduction and lower prices to customers. At the same conference, Esser-Scherbeck [2] reported that an open and liberalised German market promoted an increase in competition amongst buyers and sellers and an increase in short term energy trading. The SAPP experience to date concurs with that of Chessire and Esser-Scherbeck.

The outlook for the future regional market includes an increase in trend for deregulation and liberalisation with private equity participation. Spalding-Fecher in contribution to developing South Africa's Energy Policy promotes diversity of source as a strategy to secure national energy supply [3]. Other countries have similar strategies and the net result will be an increase in interconnectivity and cross border trading. With policy established, the ever-increasing customer pressure for environmentally friendly competitively priced electricity will stimulate and energise the market. Existing capacities will be challenged from the new lower cost renewable energy entrants and market forces will grow in dominance. The large untapped run of the river projects is now emerging as potential new sources of regional energy; for example the Inga development in the Democratic Republic of Congo. The economic renaissance of the continent gathers momentum; supported by the policies and practices of NEPAD, the New Partnership in Africa's Development.

7. References

[1] *Principles on Standard Market Design*. Edison Electric Institute. July 2002.

[2] Financial Times Conferences, 1995. World Electricity Conference: London (UK), Pearson Professional Publication, London, UK.

[3] Spalding-Fecher, R., 2002. Energy and Energy Policies in South Africa: An Overview. NER Quarterly Journal. Issue 1,2002,p 1-18

8. About the Authors

Mr. Pat Naidoo is the Senior General Manager for Eskom Transmission, South Africa. He is a Senior Member of the SAIEE and a registered professional engineer. He represents Eskom in the SAPP Executive and Management Committees. Mr Naidoo was the Chairman of the SAPP Competitive Markets Working Group that led the development of the short-term energy market. His email address is Pat.Naidoo@eskom.co.za

Dr. Lawrence Musaba is the Co-ordination Centre Manager for the Southern African Power Pool. He is an IEE Member and Chartered Engineer. Dr Musaba was a member of the SAPP Competitive Markets Working Group and led the development of the information technology systems for the operation and management of the short-term energy market. His email address is Musaba@sapp.co.zw

Mr. William Balet is the past Executive Director of the New York Power Pool and currently the USAID Senior Advisor to SAPP. Mr. Ballet was a member of the Competitive Markets Working Group and the principal advisor on short term bilateral trading. His email address is wbalet@sapp.co.zw

Mr. Alison Chikova is the Senior Engineer at SAPP in charge of Power System Studies. He is an IEE Member and Chartered Engineer. Mr. Chikova was a member of the Competitive Markets Working Group and provided leadership on transmission availability and congestion management. Email address Alison.Chikova@sapp.co.zw