August 27, 1998

USAID Sponsored Research
For the Southern African Power Pool

MODELING ELECTRICITY TRADE IN SOUTHERN AFRICA

Year 2 Interim Progress Report

August 1998

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1. Introduction

The first year of modeling with the Southern African Power Pool (SAPP) shows how increased gains, from a more flexible and freer electricity trade in the Southern Africa region, can be about $70 to $100 million per year, [1]. These results are based on the short-term model, which was built with collaboration between the national utilities of SAPP and Purdue University.

Initial findings in the second year, with the long-term model, are showing that capacity expansion costs, together with operational costs over the next 20 years, amount to about $43 billion. These initial runs indicate that much higher percentage savings will be made, compared with those which were achieved in the case of the short-run model.

This second year of modeling is a long-term generation and inter-regional transmission expansion model incorporating the data and constraints of the short-term model. There are also additional capacity expansion costs, decision-to-build variables, and numerous new long-term planning constraints. The long-term model is both chronological and spatial. It incorporates large numbers of variables from hourly and yearly time horizons for many different levels of supply and demand of electricity from numerous sites and cities in different countries. It does this by including international transmission lines (exports and imports of electricity between countries) in the model. No commercial software is available to do this. South Africa's Eskom, with its very good modeling capacity, stopped attempting to build such big models several years ago due to technical difficulties. [2, 3]

The first year of modeling activity was between the SAPP national utilities currently connected to the Southern African grid (i.e. Botswana, Democratic Republic of Congo, Lesotho, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe) and Purdue University's State Utility Forecasting Group (SUFG). The second year is building on this first year's joint work between SAPP and Purdue but now also includes working with the national utilities that are to be connected into the grid over the next few years (Angola, Malawi, Tanzania).

The first half of the second year activity can be conveniently subdivided into three sections:

- Modeling prior to the Cape Town regional workshop.
- Workshop Summary
- Post workshop modeling.

2. Modeling Prior to the Cape Town Regional Workshop

A long-term chronological and spatial model was developed, prior to the Cape Town workshop with capacity expansion data supplied from colleagues in Southern Africa. The construction of this model was in line with the computing facilities specified by the SAPP management.

The goal of the long-term model could be summarized as follows:

Embed the short-term model into a long-term model of regional generation and transmission expansion, driven by a number of representative days per year, rather than one. The chronological and spatial nature of this model makes it very large, in the order of tens of thousands of constraints, and near 1000 integer variables in addition to an even larger number of continuous variables.

Multi-regional spatial optimization takes place with generation units and transmission lines whose limited capacity can be expanded at a cost. The cost function (capacity and line expansion costs plus operational costs over 20 years) minimizes the sum of present value for all of the regions (all 12 countries). Although there are several excellent commercial software packages available on the market which help to solve the generation expansion problem, there is not one which tries to jointly solve the generation plus transmission expansion together.

Allowing for a growth in annual demand for electricity (2%, 4%, 6%) new capacity is added to the system, either as add-ons to existing generation sites or new sites altogether.

Planned unforced outages (when stations are shut down for maintenance or repair) take place during off-peak days and forced outages (emergency situations) can take place during any period. Three different methods of insuring system reliability are simultaneously employed for every year.

Since add-on generating capacity for existing sites is available in many MW sizes, add-on capacity to existing sites was considered a continuous, rather than a discrete variable (up to some given MW limit). All capital costs were annualized, and charged to each year the capacity is available, rather than fully expensed in the year of construction. To do this, a capital recovery factor CRF was used, which calculates the proper yearly charge to make for use of the equipment, over its lifetime, given a cost of capital. For instance, to recover a site expansion investment of $200,000 with interest over an equipment life of 30 years at a cost of capital of 15%, one would need to recover $30,460 per year for 30 years.

In order to reflect the fixed cost of new units (indexed ni rather than i) in the cost function, binary variables are introduced:

In addition to the thermal and hydro station options provided by SAPP members, the model considers four different types of new thermal stations based on the latest plant cost and performance data available in the U.S.

Reserve margin constraints are modified to include the impact of imports on regional reliability requirements. The level of autonomy each country wishes to maintain is specified by regional autonomy factors, AF(z).

The SAPP-Purdue long-term model has constraints which reflect technical (generation and transmission), operational, economic, and political factors. This model is realistic for multi-regional expansion purposes. The commercial packages use the load duration curve method that cannot capture the necessary generation and transmission characteristics. The SAPP-Purdue model therefore meets the stated planning needs of the SAPP management but it is a new modeling technique involving considerable computing complexities.

All of the modeling formulations can be obtained from the workshop lecture notes. [4]

3. Workshop Summary

The two week long workshop (June 29 to July 10, 1998) had delegates from nine different SAPP countries (Angola, Botswana, DRC, Mozambique, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe). There were 23 delegates with seven South African instructors and six Purdue instructors. (Appendix II).

For two days prior to the start of the workshop the Purdue and Technikon instructors worked together in finalizing the computer laboratory facilities. During the workshop all delegates and instructors worked together on the long-term model during several computer laboratory sessions.

The workshop schedule and list of participants are shown in Appendix I and Appendix II.

A comprehensive assessment of the modeling activity at the workshop is summarized in the report from the regional consultant, Peter Robinson. His summary follows.

> The SAPP-Purdue team achieved a great deal in 1997 in developing a short-run model of the SAPP inter-connected system, identifying the scope for enhanced short-term trade and quantifying associated benefits. The project for 1998 of extending the model to examine least cost investment strategies to meet growth in demand over a long time horizon (20+ years) is extremely ambitious. The expansion of generation and transmission of 12 countries (14 regions) is to be optimized in a model which must satisfy the demanding requirements of the utilities for ease of use and short computing times, while at the same time being comprehensive, yet fully comprehensible to all potential users.
>
> The Cape Town workshop was held at a stage when the full complexity of the system was still being captured in the model, thus running the risk of participants, anxious for results, becoming frustrated. The involvement of the utilities at that juncture, however, was a reflection of the determination that the model should not be designed at Purdue. The interaction between the modelers and the users at the workshop was clearly useful in ensuring that the final model will meet utility needs and that the utilities will fully

appreciate the strengths and weaknesses. Users will themselves be able to make modifications to the model to examine particular issues as these arise.

Participants were asked to identify three strengths and weaknesses of the modeling approach. The principal **strengths** are:

(1) Involvement of users - transparency and adaptability.

(2) Designed for a particular problem - the simultaneous optimization of generation and transmission to meet projected demand in the SAPP region.

(3) Cost effective - the model itself will be available at no cost to utilities; to run it will require a modest investment in a high capacity PC and GAMS software.

The solutions which emerge from the model will be rather "broad brush", and there will be always be scope for more detailed project studies to be carried out using complementary models. The SAPP-Purdue model will, however, give a clear indication of the magnitude of the cost savings from planning and operating the system on a regional as opposed to utility-by-utility basis.

The main areas of **weakness** highlighted by participants at this stage are:

(1) Input and output modules lack flexibility and user-friendliness - spreadsheet formats would be preferred.

(2) Accuracy, compatibility and reliability of the data.

(3) Sustainability: concerns about whether the model can be kept operational once the Purdue project ceases.

These points will be addressed during the remainder of the study jointly by Purdue, (point 1) and SAPP (point 2). Questions about sustainability (point 3) arise in a context of endorsement of the potential usefulness of the model. The involvement of academic researchers from the region as well as utility staff is one strategy to provide for sustainability. Linking points 2 & 3, ways of keeping a consistent and integral data base on an on-going basis will need to be institutionalized, a role which the Coordination Center might well take on once it is operational.

It is proposed to have a follow-up workshop to give adequate time to analysis of the results of the model. Potential cost-savings are clearly going be enormous when investments which will double, triple or quadruple existing installed capacity in the region are being considered. Present national-oriented plans in some cases have not even considered as options projects, which are likely to be optimal from a regional perspective. It is to be hoped that the utilities will approach the regional solution with open minds, and not be tempted to so constrain the model from the start that the result that is produced is close to what is already contained in their national system development plans. The full extent of the potential benefits of a regional investment strategy need to be quantified. Utilities and governments can then be confronted with the costs of continuing with an orientation towards self-sufficiency, which is clearly evident in current investment plans.

Uncertainty is a big issue in considering the results of the model. The idea of developing a “flexible strategy” that will perform better than a supposedly “optimal” solution when demand conditions change, is important. To arrive at a robust investment sequence, the model must provide as output details of the investment sequences implicit in any least cost solution. In examining the details of the investment sequence, attention is to be given to project lead times, environmental and financing issues. How the initial “flexible strategy” can be refined in future in response to the actual trends in the growth of demand which emerge is also to be considered. Finally, but most importantly for winning countries over from autarchic inclinations, the options for achieving an equitable distribution of the gains from regional cooperation need to be elaborated.

The workshop report from the Eskom delegates further compliments the above summary and this is included as Appendix III. Reports from other delegates can be obtained directly from them (Appendix II) or from Barbara Beaver (Em. barb@ecn.purdue.edu).

4. Post Workshop Modeling

Different approaches are currently being pursued to improve the model. The formulation changes and new constraints are listed in Appendix IV of this report. Major changes can be put into the three following categories:

1. Improve the computation speed by discarding unnecessary integers, using different solution algorithms, and designing a more suitable PC environment for the model.
2. Improve the data quality, including demand data, fuel price data, expansion cost data, etc.
3. Preparation of users manual of the model. This is in progress and a final version will be ready by the end of the year.

No "silver bullet" has been found as yet, computation speed-up will likely be a gradual progress, and improvement will continue with further work on the model in 1999.

Several major experiments have been conducted at Purdue since the return from the Cape Town workshop involving the incremental introduction of the model changes recommended at the workshop. Modifications to the model accuracy and any increase in binary variables considerably lengthens the running time.

At the workshop an upgraded (increased RAM) Pentium II had been used for full 24 hour model test runs. (One-hour models had been used by the delegates in order to have a quick running time of about five-minutes, and to get an understanding of how the model is structured and operates). The 24-hour model, at the workshop had taken 13 hours to run with a 3.5% accuracy and 51 hours with a 1% accuracy. On returning to Purdue the 24 hour 1% accuracy model obtained a reduced running time of 34 hours and an objective function of about $43 billion. With all recommendations from the workshop nearly implemented on the 24 hour, 1% accuracy model, the running time was considerably increased primarily due to the attendee request that additional capacity be added in fixed amounts, rather than variable amounts. With the model having almost 1000 binary/integer variables and 0.5 million continuous variables it becomes enormously large.

To accommodate such a large model on a PC three avenues of work are now being implemented:

a) The processor, bus, and memory of the PC are all being speeded up with the building of a more suitable machine to handle the model. A BX class board running with a 100 MHz bus, 350 MHz Pentium 2, ultra wide disk drive and RAM of 384 MB to 512 MB is being constructed. It will operate with Windows NT. This will make improvements to the model running time.
b) Relaxation of integer variables. The integer and binary variables are largely responsible for the long running times. Peaking generating stations (gas turbine options) could be considered as continuous variable options. NSA is allowed to add several large new coal units while other regions in the model are no longer given this option.
c) A reduction in the project options for each period is being considered, but only after assurance that it will not alter the optimal solution.

The SAPP specified capacity expansion projects are listed in Appendix V and VI. Some discussion has taken place regarding which projects should be included in the model and more work in this area is being planned. Appendix V is an "official" SAPP list of projects and Appendix VI is the list compiled, so far, from dialogue with individual SAPP utilities.

The initial section of a user manual has been written which includes a transparent, simplified version of the SAPP network for new users of the model. The full manual will, of course, develop the full-blown model.

5. Future Work

The second half of year 2 modeling will involve finally resolving the computing complexity. At the same time, it will need to meet the SAPP planning requirements. The future work is prioritized as follows:

a) Finalize the model accuracy and computer complexity issues.
b) Confirm details of transmission and generation capacity expansion projects.

c) Base the demand growth rates on the values in Table 1 below (with SADC regional, low, medium, and high values of 2%, 3.8%, and 5.7%).
d) Develop user friendly input and output procedures to the model.
e) Write up the user manual for the model intended for managers, planners, and engineers.
f) Interact with SAPP utilities over (d) and (e).
g) Presentation of long-term model results to SAPP Management (February 1998?).
h) Plan a three-day follow-up result workshop.
i) Develop a policy for further development, maintenance and sustainability of the model from within the SADC region.

In the fall of 1998 the modeling accuracy and computing requirements should be resolved. SAPP and Purdue have also to finally agree on the total list of projects, and model modifications that are to be incorporated into the long-term model.

By the start of 1999 user friendly input and output protocols will be in place together with a user manual. Following the September 1998 SAPP quarterly meeting (in Harare) it is expected that the specific requirements of the user manual will be finalized. The interface between user and model, and the clarity of the manual will be assessed by SAPP colleagues during the early part of 1999. If further improvements to each are recommended, then these can be undertaken in 1999, well prior to the workshop discussed below.

It is recommended that a special three-day workshop be organized to discuss the results from the second year of modeling. The dates and venue need to be agreed upon.

The development, maintenance, and sustainability of the long-term model needs further thought. It has been proposed that regional academics could pick up an active part of the research load. Engineers in the utilities already carry heavy workloads and do not have time to work on the model on a continuous weekly basis. Full-time modelers are needed for the SAPP coordinating center in Harare, but until these are in place the universities in the region have manpower, time and facilities to pursue the modeling on behalf of SAPP. It could be proposed that USAID provide funding to assist in the development of modeling capacity at several universities in the region (possibly the three big hydro dominated countries, DRC, Mozambique, and Zambia, and the two major thermal countries, South Africa and Zimbabwe). The value of contributions from researchers in South Africa and Zimbabwe was demonstrated at the Cape Town workshop. The development policy and wider implementation of the model could provide core activity in a plausible third year of research between SAPP and Purdue.

As the modeling and computing issues become resolved in 1998 it is essential that the project data, loaded into the model, is checked and found to be completely acceptable to each utility. Many major new projects are being proposed for the first decade. The much longer-term projects, planned for the second decade and beyond, are understandably less crystallized in the minds of the SAPP planners.

The SAPP official list of new projects (Appendix V) proposes tentative dates up to the year 2012. The long-term model is looking at a 20-year time horizon with the year 2000 as the base year. Both lists for the generation expansion and new international connections make no reference to developments on the River Cargo. This is a serious omission for any long-term policy modeling.

At the Cape Town workshop the SNEL delegates discussed their plans for implementing Grand Inga (39,000 MW) with major lines to Egypt (4,000 MW) and South Africa (2,000 MW). It would speed up the process of obtaining meaningful results from the model if the SAPP management can provide a fully comprehensive list of projects that might be considered during the next 20 to 25 years. Can SAPP provide such a comprehensive list before December 1998?

New projects were discussed at the Cape Town workshop. Delegates from each utility briefly presented their long-term plans (verbally with some documentation). The initial list of projects, compiled at Purdue, (as a result of dialogue with each utility) and shown in Appendix VI will need time to be made complete. Some follow-up will be needed to confirm the discussion at Cape Town.

The formulation and computing requirements of the model will be completed in 1998. Final compilation of projects, provision of an acceptable user manual, and model maintenance and development issues are probably going to carry over into 1999.

TABLE 1: SADC & SOUTHERN AFRICA POWER POOL - GDP & CAPACITY GROWTH RATES - 1996-2020

1996-2020	Maximum Demand 1996 MW	GDP Growth (annual average rates)			Electricity to GDP Elasticity (underlying)	Electricity Intensive Projects MW	Demand Side M'ment by 2020 (H) MW	Maximum Demand (internal - 2020)			Maximum Demand growth rates 1996-2020			Comments
		LOW % p.a.	MEDIUM % p.a.	HIGH % p.a.				LOW MW	MEDIUM MW	HIGH MW	LOW % p.a.	MEDIUM % p.a.	HIGH % p.a.	
Angola	181	1.5%	3.0%	6.0%	1.26	1000	38	765	1111	2004	6.2%	7.9%	10.5%	Mining & mineral beneficiation
Botswana	222	3.6%	4.2%	5.9%	1.01	60	47	529	606	903	3.7%	4.3%	6.0%	Industry plants
Lesotho	76	3.5%	6.0%	8.0%	1.04		16	171	312	501	3.4%	6.1%	8.2%	
Malawi	164	2.0%	3.0%	5.5%	1.16		34	268	346	693	2.1%	3.2%	6.2%	
Mozambique	192	3.0%	5.0%	7.0%	1.36	2000	40	1481	2299	3662	8.9%	10.9%	13.1%	MOZAL, I&S (Maputo), Moatize Coal, other minerals
Namibia	321	3.5%	5.0%	6.0%	1.02	1000	67	1210	1704	2265	5.7%	7.2%	8.5%	Mining developments
South Africa	26382	2.0%	3.8%	5.5%	1.05	1500	7900	40244	62199	95108	1.8%	3.6%	5.5%	Mining & mineral beneficiation
Swaziland	140	2.6%	3.6%	4.6%	1.04		29	251	315	400	2.5%	3.4%	4.5%	
Tanzania	412	2.4%	4.0%	5.3%	1.30	500	86	1068	1672	2452	4.0%	6.0%	7.7%	Mining developments
Zambia	1028	2.4%	4.0%	5.8%	1.09	250	215	1928	2866	4511	2.7%	4.4%	6.4%	Mining back to capacity
Zimbabwe	1744	2.8%	4.0%	5.7%	1.04	400	366	3490	4626	6982	2.9%	4.1%	5.9%	Mining & mineral beneficiation
SADC tot/weighted av	30862	2.1%	3.8%	5.6%	1.06	6710	8839	51406	78055	119483	2.0%	3.8%	5.7%	
South Africa	26382	2.0%	3.8%	5.5%	1.05	1500	7900	40244	62199	95108	1.8%	3.6%	5.5%	
Rest of SADC	4480	2.7%	4.1%	5.8%	1.10	5210	939	11162	15856	24374	3.6%	5.0%	6.9%	
Scenario probabilities											0.40	0.45	0.15	

Compiled by: Peter B. Robinson, July 1998

References

[1] F.T. Sparrow, William A. Masters, Zuwei Yu, Brian H. Bowen, Peter B. Robinson, et al. "Modeling Electricity Trade in Southern Africa, First Year Report to the Southern African Power Pool." Lusaka, Zambia, March 3-4, 1998

[2] J.L. Pabot, Eskom modeling, Johannesburg, South Africa. E-mail message of August 12, 1998.

[3] Eskom's Modeling Report, Cape Town Regional Modeling Workshop, Cape Technikon, South Africa, June 29 - July 10, 1998.

[4] F.T. Sparrow. "The Long-Run Model." Purdue (SAPP workshop, Cape Town, South Africa, June 29 - July 10, 1998.

Appendix I
SAPP_Purdue Regional Modeling Workshop
SCHEDULE

	Morning	*Afternoon*
Mon., June 29	10:00 a.m. Lectures on short-term model (Sparrow)	Lectures on short-term model - continued (Sparrow) Intro to GAMS and short-term model coding (Bowen)
Tue., June 30	8:30 a.m. - Run short-term model	Continuation of a.m. session
Wed., July 1	10:00 a.m.- Intro/workshop objectives (Sparrow) Short-term model results update (Bowen)	Long-term model -- Lectures 1 and 2 (Sparrow) (fixed trade) Intro to long-term model coding (Nderitu)
Thu., July 2	Site Visit to Koeberg Nuclear Power plant	2:30 p.m. – Tutorials on "fixed trade" models (PU/CT staffs)
Fri., July 3	8:30 a.m. - Long-term model -- Lecture 3 (Sparrow) (free trade) Reliability lecture (Gotham) Hydro lecture (Yu)	Model modification session 1-- break up into groups by topic: Thermal (Sparrow), Hydro (Yu), Transmission (Nderitu), Reliability (Gotham), Demand (Robinson/Bowen), Other Start tutorials on full models
Sat., July 4	8:30 a.m. – Discuss recommendations of modification groups; fix I in structure	OFF
Sun., July 5	OFF	OFF
Mon., July 6	8:30 a.m. - Report impact of structural change; begin runs of full model	Data input (each utility to confirm correct data in 24 hour LT model) & individual runs
Tue., July 7	8:30 a.m. - Discussion of country results; fix II in structure	Collective discussion
Wed., July 8	8:30 a.m. - Runs of capacity expansion scenario	Site Visit: pumping station Evening: Group Dinner at Stellenbosch
Thu., July 9	8:30 a.m. - Presentation of Purdue analysis of capacity expansion scenarios	Discussion of individual vs. collective capacity expansion plans, distribution of gains
Fri., July 10	8:30 a.m. - Further discussion of gains and equity, as necessary	Wrap-up Session Evening: Departure of Purdue staff

Appendix II
List of Participants
Cape Town Workshop, June 29 – July 10, 1998

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Appendix III
SAPP – Purdue Regional Modeling Workshop
Eskom's Report

General

Eskom does not have any model able to optimize simultaneously the expansion of the SAPP generation and transmission systems, and does not know any commercial model able to do this.

Therefore Eskom would support any model able to do this joint expansion, as long as the model assumptions, algorithms, and capabilities are adequate enough for the results to be reasonable correct. The value to Eskom of the output of the model should also exceed the cost of the resources required to run the model.

Overall Comments

Purdue's long term model, as presented at the July workshop, is able to optimize simultaneously the expansion of the SAPP generation and transmission systems, and could be used by Eskom and/or the SAPP planners as is, to get a first draft of the optimal SAPP expansion plan.

However the Purdue model simulates the SAPP system, its load, and its operation in a simple manner. The results of the model, i.e. the draft SAPP expansion plan, must be further checked by the user, and the plan refined using the more accurate complementary models available to the user.

Eskom would like to install the Purdue model on one of its PC for testing purpose.

Main simulation options

The model simulates the SAPP generation and interconnection system, i.e. the supply side system. It does not simulate Demand side management.

The main simulation options seen to have been selected to keep the model simple, small, and fast: e.g. Linear model, 6 days/year load simulation, 5 representative years per study period, no probabilistic modeling of the units outages, station modeling only (no individual units), etc.

All these simulation options seem reasonable and compatible with the intent of the model (simple, small, fast), but their selection has obvious implications for the accuracy and credibility of the results: the resulting pool expansion plan can only be considered as a draft/rough plan. It should be further checked and developed using more accurate software.

Nevertheless, the model should, as a minimum, give the following options to the user: More than 2 seasons/year, more than 3 days/season, a different load profile for each of the 6 days for each year, simulation of all years, simulation of pumped storage units, and DSM programs (direct load control, energy efficiency, interruptible load, strategic load growth) both as existing resources, and a future expansion options.

Appendix III (continued)

Algorithms and programming

The algorithms, e.g. the linear equations, seem reasonable for a linear model.
The programming code makes an excessive use of variables for sheer convenience (to minimize programming time), e.g. it allows each country to have interconnections with each other country, which is unnecessary, each country can build up to eight generating options, which is too many for most of the countries, but too few for Eskom.

The model is built around a single large linear model, which can become very big, and limits the simulation options (e.g. number of years). A decomposition of the problem into smaller subproblems cloud be useful.

Model run

From small runs made at the workshop, a full run would take a long time on a standard PC (Pentium 1, 133 MHz, 32 MB memory) for a reasonable accuracy (convergence ratio < 0.001).

Input/output interfaces

The program is not user friendly:

There is only limited documentation available to the user.

The input files are flat text files. This is not easy to use for users accustomed to modern data input techniques: data bases, graphical interfaces.

The output files are very limited and inadequate to enable the user to have a fast understanding of the results, and to find the cause of anomalies in the results.

PC Platform

The model is intended to run on a PC Pentium II, 266 MHz, with 512 MB memory, which is a luxurious platform.

The model should be able to run, even if slow, on the standard PC available to the SAPP staff, usually a PC Pentium I, 133 MHz, 32 MB memory.

Appendix IV
Model Revision Status
(Summary from Cape Town Workshop – August 1998)

UC = under consideration
C = complete
IP = in process

	Status	Section "DATA"
1.	IP (delay)	Change from every 5 years to 5 two-year periods, two 5-year periods
2.	UC	Require the discount rate ("int") in the objective function to be the same as the cost of capital in the CRF function
3.	C	Allow CRF to be function of the country and the lifetime of the equipment, e.g., CRF(z,equip type)
4.	C	Allow demand growth rates to vary by period, as well as country
5.	C	Allow unforced outages for thermal on all days except winter peak day
6.	IP	Allow unforced outage for hydro in dry season only
7.	IP	Allow pumped storage and pumped storage expansion in the model
8.	IP	Make UFOR for new plants to reflect yearly %

Status		Section "DEMAND"
IP	1.	Allow independent 24-hour patterns for 6 day types rather than scalar mult.
UC	2.	Allow dgrowth to be indexed by day type, as well as country
C	3.	Allow yearly peak demand to be obtained from 24-hour table, not PeakD(ty,z)
IP	4.	Clarify use of DLC(z) – inconsistent now (Tom will send SAPP our convention)
UC	5.	Allow DSM(z) to enter by altering 24-hour load shape as well as subtracting from demand; allow DSM(z,th) costs to enter O.F.
IP (de-layed)	6.	Split DRC into WDRC and SDRC (see SNEL report)
IP	7.	Summer = 9 months; Winter = 3 months

Appendix IV (continued)

Status		Section "HYDRO"
C	1.	Make extension of Kariba S. conditional upon start of Batoka, not vice versa (add $Y(ks) \leq \overline{M}Y(B)$
UC	2.	Add hydrological data (water in flow, turbine discharge, evaporation)
UC	3.	Add pumped storage for Tanesco
C	4.	Derate all capacities by FOR
IP	5.	Delete INGA III (3,500 MW) and insert GRAND INGA (39,000 MW)
	6.	Zim Kariba capacity will be increased to 750 MW by 1999
	7.	Equal share of Kariba water energy allocated to Zambia and Zimbabwe
	8.	Water energy inflows may be tabled, not as parameters at the time being
	9.	Reduce the integers associated with new hydro; e.g., Grand Inga only for years after 2010, etc.
	10.	All other hydro projects completed by 2000 should be treated as old -- e.g., not in optimization

Status		Section "THERMO"
IP	1.	Require all additions to new and old plants to be multiples of plans of a fixed size -- e.g., new thermal capacity can be 0MW, 300MW, 600MW, 900MW, etc. -- rather than continuous
C	2.	Allow fixed costs to vary by country, as well as plant type
IP	3.	Allow first capacity increment and cost to differ from additional capacity and cost increments for new plants
IP	4.	Allow NSA to add more than 2 plants/types per period; allow more large coal plants -- up to 8
C	5.	Allow plants under construction to enter in year of completion as old plants (no fixed cost); no thermal plants in this situation
IP	6.	Allow for decommissioning/derating of old plants (Kevin to do)
C	7.	Derate capacity limits by (1-FORPGO) and (1-FORNα)

Appendix IV (continued)

Status		Section "THERMO" (continued)
UC (doubt-ful)	8.	PGmin eliminated
UC	9.	Add NSA mothballed plants as new plants with fixed start-up cost
	10.	Allow heat rate for large coal and small coal plants to be different

Status		Section "TRANS"
IP	1.	Require additions to new and existing line capacity to be multiples of a fixed capacity
UC	2.	Allow Angola-Zambia, Nam-Zim
IP	3.	Make clear line resistance considered in calculating line loss (in write-up)
IP	4.	By year 2000, assume interconnectors between Zam and Tan, Zam and Mal, Moz and Mal
UC	5.	Make FOR distance-sensitive and enter into capacity constraint, not same constant for all lines
UC	6.	Consider DRC/Ang/Nam/RSA line after 2010

Status		Section "RESERVE"
C	1.	Eliminate first reliability constraint (Lecture 1, p. 8, equation C3)
C	2.	Modify second (worst case single outage) to read $\sum_{i} \text{thermal capacity} + \sum_{ih} \text{hydro capacity} + \sum_{z,zp} \text{net imports} \geq \text{Dyr}(\text{ty}, \text{winter}, \text{peak}, 19, 2)\text{DLC}(z) + \text{MaxG}(z)$
IP	3.	Modify third (reserve margin) to read $\sum_{i} \frac{\text{thermal capacity}}{1+\text{RES}(\text{therm})} + \sum_{i} \frac{\text{thydro capacity}}{1+\text{RES}(\text{hydro})} + \sum_{z,zp} \frac{\text{net imports}}{1+\text{RES}(z,zp)} \geq \text{Dyr}(\_)\text{DLC}(z)$
C	4.	Allow FOR and UFOR to vary by country and plant type and site

Appendix IV (continued)

Status		Section “RESERVE” (continued)
C	5.	Eliminate SAPP reliability constraints
UC (will be case study)	6.	Forbid net imports to enter into reliability constraints (if do, reduce benefits of trade!)
UC	7.	Add load carrying capability as third reserve constraint

MODEL CHANGES

IP	1.	Make entry of Y(ty) into capacity constraints consistent between thermal, hydro, trans
?	2.	For new construction in year ty, enter in OF present value from ty to Y of all “rentals”, e.g., $\sum_{\gamma=ty}^{Y} \frac{(CRF)(\text{Fixed Cost})(Y(ty))}{(1+\text{int})^{\gamma}}$
UC	3.	Make input/output tables user-friendly -- spreadsheet format -- windows format
C	4.	Set accuracy to 1%
UC	5.	Test interior point method for L.P.

GENERIC CHANGES

UC	1.	Allow environmental impact to enter model
IP	2.	Allow gains from joint planning for each country to be specified
C	3.	Model output should include breakdown of costs by type by country
IP	4.	Model country output should include expansion schedules by country and by plant

Appendix V

SAPP Official List of Capacity Expansion Projects

SOUTHERN AFRICAN POWER POOL
NEW GENERATING PLANT

Table 3a

Year	Country	Powerstation	Number of Units	Unit Size (MW)	Total Added MW)	Cost US million	Type T/H
1996	South Africa	Majuba 1	1	612	612		T
1966	South Africa	Arnot 3 Recommission	1	330	330		T
1997	Zimbabwe	Hwange Upgrade	1	84	84		T
1997	South Africa	Majuba 2	1	612	612		T
1997	South Africa	Arnot 4 Recommission	1	330	330		T
1997	Tanzania	Ubungo	1	30	30		T
1997	Tanzania	IPTL	4	25	100		T
1998	Lesotho	Muela	3	24	72		H
1998	South Africa	Majuba 3	1	612	612		T
1998	South Africa	Arnot 5 Recommission	1	330	330		T
1999	Tanzania	Kihansi	3	60	180		H
1999	South Africa	Majuba 4	1	667	667		T
1999	South Africa	Arnot 6 Recommission	1	330	330		T
1999	Malawi	Kaphichira Phase 1	2	32	64		H
2000	Angola	Capanda	2	130	260		H
2000	South Africa	Majuba 5	1	667	667		T
2002	Zimbabwe	Hwange 7	1	330	330		T
2001	South Africa	Majuba 6	1	667	667		T
2001	Zambia	Itezhi-Tezhi	1	80	80		H
2002	Zambia	Kafue Lower	1	200	200		H
2002	Tanzania	Da-es-Salaam	1	50	50		T
2002	Malawi	Kaphichira Phase 2	2	32	64		H
2002	Namibia	Kudu	1	650	650		T
2003	Zambia	Kafue Lower	2	200	400		H
2003	Malawi	Lower Fufu	1	45	45		H
2003	Zimbabwe	Hwange 8	2	330	660		T
2003	Mozambique	Mepanda Uncua	5	400	2 000		H
2004	Angola	Capanda	2	130	260		H
2004	Tanzania	Rumakali	4	51	204		H
2004	Malawi	Lower Futu	1	45	45		H
2004	Namibia	Kudu	1	650	650		T
2004	Zimbabwe	Batoka Hydro	1	800	800		H
2006	Tanzania	Mpanga	4	40	160		H
2008	South Africa	Komati 1, 2 & 6 Recommission	3	2x90, 1x114	294		T
2008	South Africa	Grootvlei 1-3 Recommission	3	190	570		T
2009	Zimbabwe	Sengwa	1	330	330		
2009	South Africa	Komati 3,4,7 & 8 Recommission	4	2x90, 2x114	408		T
2009	South Africa	Grootvlei 4-6 recommission	3	1x180, 2x190	560		T
2009	South Africa	Camden 1 Recommission	1	190	190		T
2010	South Africa	Camden 2-4 Recommission	3	190	570		T
2010	South Africa	Braamhoek 1	1	333	333		H
2003	Zimbabwe	Gokwe North	2	350	700		T
2004	Zimbabwe	Gokwe North	1	350	350		T
2005	Zimbabwe	Gokwe North	1	350	350		T
2009	Zimbabwe	Batoka South	1	200	200		H
2010	Zimbabwe	Batoka South	1	200	200		H
2011	Zimbabwe	Batoka South	1	200	200		H
2012	Zimbabwe	Batoka South	1	200	200		H

Appendix V (continued)

SOUTHERN AFRICAN POWER POOL
New International Transmission Lines

Table 3b

Year	Country from	Country to	Substation from	Substation to	Voltage	Route Length (km's)	Transfer Power	Cost US $ Million
1997	Mozambique	Zimbabwe	Songo	Bindura/Dema	400kV	250	500MW	
1998	South Africa	Swaziland	Prairie	Zombodze	275kV	150		
1998	Zambia	Tanzania	Pensulo	Mbeya	330kV	650	230MW	150
1998	Mozambique	South Africa	Songo	Apollo	D.C 525kV	1 420	2 000 MW	
1999	Mozambique	Swaziland	Matola	Zombodze	275kV	180	200MW	25
1999	South Africa	Mozambique	Arnot	Maputo	400kV	220	900MW	
1999	South Africa	Mozambique	Camden	Maputo	400kV	220	900MW	
1999	South Africa	Namibia	Aries	Kokerboom	400kV	420		
1999	Zambia	Zaire	Luano	Karavia	200kV	144	375MW	
2000	Mozambique	Malawi	Matambo	Blantyre West	220kV	200	300MW	40
2003	South Africa	Swaziland	Prairie	Zombodze	275KV	150		

Appendix VI

Compiled List of New Projects – (From Correspondence between SAPP Utilities and Purdue)

July 30, 1998

SAPP New Transmission Lines

Project # **Connecting Nodes**	**Line Type (kV) / & Capacity (MW)**	**Capital Cost ($US Millions)**	**Commissioning Year**	**Line Length (km)**
(1) SMoz – NSA/Swaz	Phase1 ***** 450 MW # Phase2 400 MW #	$ 130.57 #	2000 # 2003 #	150 *
(2) RSA(SSA)/Aries to Nam/Auas	400 kV 1630 MW [JLP]	$ 100 (Rand 592 m)[JLP]		875
(3) Nmoz – Mal *****	220kV 300 MW #	$ 40.02 #	2000[M]	175 *
(4) NMoz – SMoz *****	330 kV AC [zy] 1600 MW	$ 800.0 (10% loss)[zy] *{$ 500.0}* [pr]		1200*
(5) Mal – Zam	330kV 240 MW [M]	$ 98.84 [M] *{412 $/kW}*[pr]		340 [M]
(6) (DRC(WDC)/Inga to Egypt	4000 MW (2*2000)[CT]			
(7) (DRC(WDC)/Inga to Ang/Capanda	330 kV AC [zy] 2000 MW*	$ 330.0 (2% loss)[zy]		520*
(8) Ang/Capanda to Nam/Kokerboom	330 kV AC [zy] 2000 MW*	$1211.0 (14%loss)[zy]		1900*
(9) DRC(SDC)/Kolwezi to Zam/Kitwe	230 kV 1800 MW [zy] *{250MW}*[pr]	$ 227.0 (15%loss)[zy] *126 $/kW* *{$40.0, 160 $/kW)*[pr]		520*
(10) DRC(WDC)/Inga to DRC(SDC)/Kolwezi				
(11) Tan to Zam	330 kV 200 MW	$ 150.0		650

Source Note:
***** Already committed, pr May 26, 1998
* zy-bhb, May 20, 1998
M Escom, Fax, May 15,1998, (Capacity 200MW & cost $32million),
** ZESA, Email, May 6, 1998
zy *Z,Yu, May 26, 1998*
pr *Peter Robinson, May 26, 1998,*
EDM, Fax, May 5, 1998
CT Cape Town, July 1998
JLP *Pabot email July 15, 1998*

Data with no source provided assume taken from SAD-ELEC

Appendix VI (continued)

SAPP Thermal Capacity Expansion Projects

Project # **COUNTRY / Utility**	**Site Name**	**Plant Type**	**Capital Costs ($US Millions)**	**Commissioning Year**	**Capacities MW**	**Heat rate (Btu/kWh) & Fuel Cost ($/Btu)**
(9) Angola / ENE						
(10) Botswana / BPC	Moropule (Extend)	Coal-Bitumous	$ 300 *(1250 $/kW) ~* *{$350, 1458 $/kW} pr*	2003 ~	2x120 = 240 ~	
(11) Namibia /NamPower	Kudo (New)	Gas C.Cycle	$ 650pr *{866 $/kW}* *{500 $/kW} pr*		*{1300 MW}pr*	
(12) Tanzania / TANESCO						
(13) Zimbabwe / ZESA	Hwange 7 & 8 (Extend)	Coal-Bitumous		2003/4**	2x300 = 600 **	
(14) Zimbabwe / ZESA	Gokwe North/Sengwe (New) **	Coal-Bitumous			3x300 = 900 ** 1x300 = 300 ** 300 MW pr	
(15) RSA	Majuba units 4-6	Coal-Bitumous		1999 2000 2001	612 612 612	

Note: OMLC – Operations, Maintenane, Labor, Chemicals

Source Note:
+ *NamPower, Email, May 5, 1998*
~ *BPC, Emails, May 5, 1998 & May 21, 1998*
** *ZESA, Email, May 6, 1998- **CONFIDENTIAL DATA***
pr *Peter Robinson, May 26, 1998*

Appendix VI (continued)

SAPP Hydropower Capacity Expansion Projects (New & Old Sites)

Project # **COUNTRY /Utility**	**Site Name** (New / Extend)	**Capital Costs ($US Millions)**	**Commiss -ioning Year**	**Capacities** **MW**	**Inflow Rate (cu m per hour)**
(17) Angola / ENE	Capanda (New)	$ 300 *{1154$/kW}pr*	2000	260 MW	
(18) DRC / SNEL	Inga III (Extend)	$ 1000 *{ 286 $/kW}pr*		3500MW	
(19) Lesotho	Muela (New)		1998	72 MW	
(20) Malawi / Escom	Kapichiri (New) Phase I & II Shire River	$ 120.0 M *{1875 $/kW}* $ 24.0 M *{ 375 $/kW}*	2000 M 2003 M	64 MW M 64 MW M	
(21) Malawi / Escom	Lower Fufu	$ 169.0 M *{1352 $/kW}*	2015 M	125 MW M	
(22) Mozambique / EDM	Cahora Bassa North (Extend)	$ 800 H		600 MW H	
(23) Mozambique / EDM	Mepandua Uncua (New) - *IPP*	$2,500 H*	2004 #	1600 MW #	
(24) Namibia /NamPower	Epupa (New)/ Kunene River	$ 408 *{1073$/kW}* *{983 $/kW}*	2005	380 MW + *{415 MW} pr*	
(25) Swaziland / SEB					
(26) Tanzania /TANESCO	Lower Kihansi (New)	$ 440 *{2444 $/kW}*	2000 ##	180 MW ##	
(27) Zambia / ZESCO	Kafue Gorge Lower (New)	$ 430.6 $ *{718 $/kW}*	2004 $	600 MW $	1,260,000 A
(28) Zimbabwe / ZESA	Kariba South (Extend)			300 MW pr	
(29) Zimbabwe / ZESA Zambia / ZESCO	Batoka (New) Run of River (ZESA & ZESCO total 1600 MW)	$1100.76 ** *{1376 $/kW}* *Dam & 2 stations* *$ 1101 pr*	2010** 2011** 2013** 2014**	1x200 = 200 ** 1x200 = 200** 1x200 = 200** 1x200 = 200** 800 MW	

Note: OMLC – Operations, Maintenane, Labor, Chemicals*Source*

Source Note:

#	*EDM, Fax, May 5, 1998*	##	*TANESCO, Email, May 15, 1998*
+	*NamPower, Email, May 5, 1998*	pr	*Peter Robinson, May 26, 1998*
M	*Escom, Fax, May 15, 1998*	H	*EDM fax, June 17,*
$	*ZESCO, Fax, May 4, 1998*	A	*Alex, ZESCO Email, May 28,1998*
**	*ZESA, Email, May 6, 1998*	H*	*EDM fax, June 17, includes line to Maputo*