

Benefits to South Asia from an Integrated Electricity Market Infrastructure

Brian H. Bowen, F.T. Sparrow, Zuwei Yu, Geoff Granum
Institute for Interdisciplinary Engineering Studies, Purdue University
West Lafayette, IN 47907-1293, U.S.A., Fax: 765-494-2351

Dhaka, Bangladesh, July 19-23, 2003

Abstract

The countries of South Asia look towards improved supplies of electricity, with increased reliability, as being a critical component for regional economic growth. In Bangladesh, Bhutan, and Nepal only a minority of the population have access to electricity. Compared with more developed economies the kW per capita, of the three countries, is unacceptably low. The need for more generation capacity across the whole region raises the question as to what is the most economical and beneficial planning strategy for improving the electricity supplies, in the region, for the next decade.

Some obvious solutions will include utilization of hydropower potential in Bhutan and Nepal as well as maximizing the use of natural gas (combined cycle stations) in Bangladesh. The construction of new international transmission lines, role of independent power producers (IPPs), and utility restructuring are major energy planning issues currently facing the region. This paper outlines the benefits gained from greater regional cooperation in energy trading as the debate for a South Asia Power Pool gathers momentum. Secondly a case is made for the creation of decision support tools for energy planners that will assist institutions across South Asia in prioritizing cost effective projects, trade and tariff policies, and attract private and international investors.

1. Introduction

Purdue University has extensive experience in electricity trade modeling with utilities and regulatory bodies of the Mid-West U.S.A. the Southern African Power Pool (SAPP), and the West African Power Pool (WAPP). Results show potential regional long-term (LT) cost savings in the order of 6% to 13%. In the SAPP short-term model annual savings of \$70 to \$100 million were predicted for a free trading environment, between the 12 member states, compared with the limited bilateral electricity trade contracts [1,8]. The Purdue long-term (LT) models incorporate economic and engineering parameters for both generation and transmission, typically over a 10 to 20 year planning horizon.

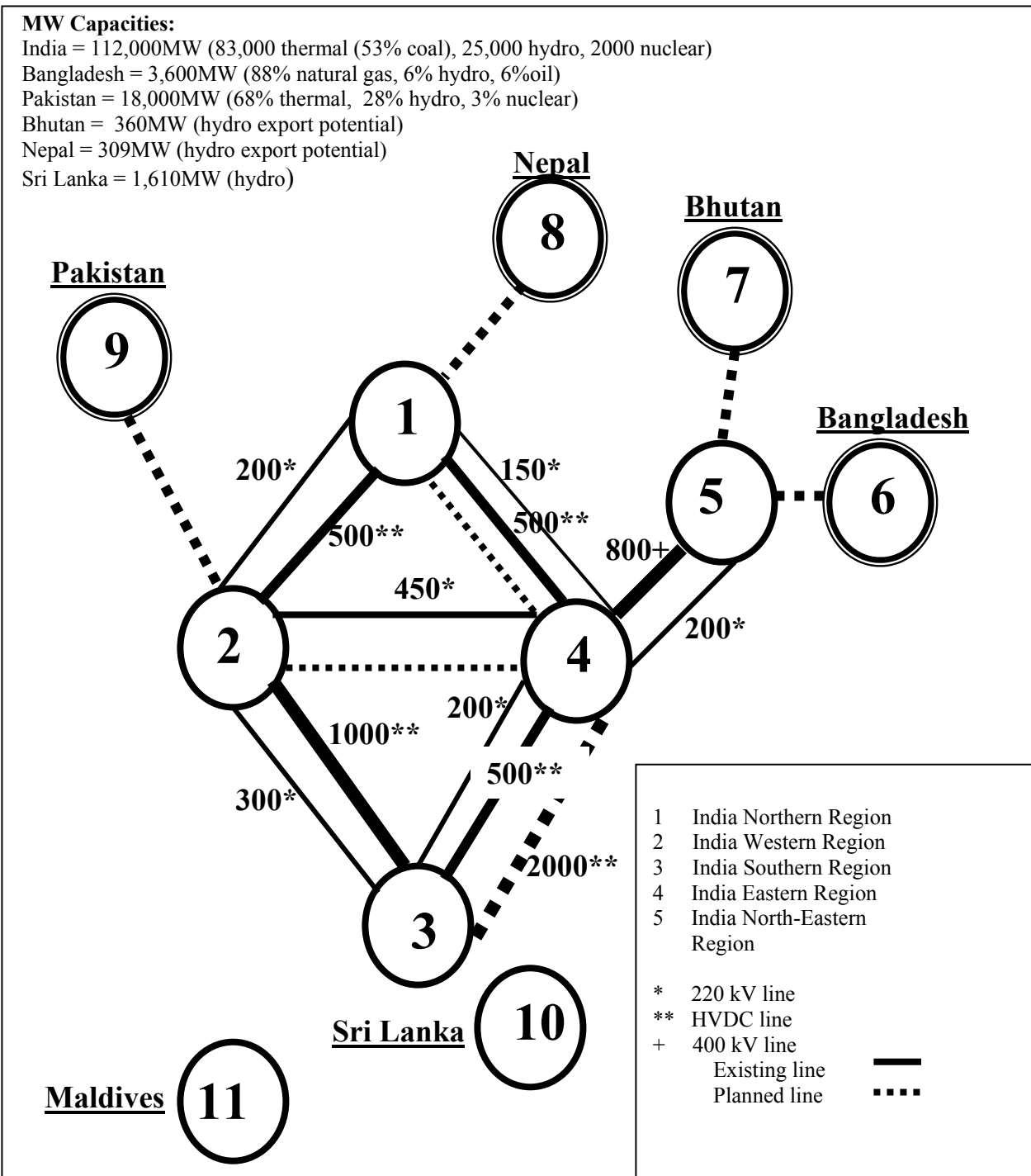
This paper provides a background to policy analysis work being done at Purdue and outlines sophisticated decision support tools that could have a role to play in the development of the South Asia regional energy markets. Several important questions are raised, including what levels of trade or inter-dependence might be initially expected among member states of a fully interconnected

integrated regional South Asia power pool. Interconnection with India will facilitate significant MWh imports of hydropower from Bhutan and Nepal. The role of IPPs and the thermal hydro balance are key issues for each country of the region. The Purdue economic decision support models employ cost minimization requiring thermal station, hydropower station, and transmission line data for the region with financial variable and capital cost data.

2. Background & Benefits from Improved Regional Energy Trade

To allow free movement of energy (electricity and natural gas) between countries an integrated energy grid must exist across the region. Alternative forms of regional markets for electricity (loose or tight power pool) across South Asia can be analytically assessed. This can be achieved through mathematical economic modeling of power pools, considering existing and proposed generation and transmission facilities across the region. A tentative initial regional model is illustrated in Figure 1. First of all however let us consider the benefits of power pooling.

Figure 1. Southern Asia Inter-Regional Transmission Capacities (MW)



Time and again, it has been observed that the rationalization and harmonization of regional economies have started with cooperative ventures involving specific commodity sectors. The European Common market has its roots in the Iron and Steel Community agreements in the early 1950s. The North American Free Trade Agreement (NAFTA) was preceded by a host of commodity agreements, including electricity. The growing economic integration of the Southern African Development Community (SADC) is both a cause and an effect of the success of the Southern African Power Pool (SAPP). It is anticipated that, as in the case of SADC, regional energy trade modeling will help to show the major gains from improved regional energy partnerships in South Asia.

2.1 Policy analysis of trading gas by wire

There is much interest on whether to ship energy across a region either by line or by pipe to send electricity or send natural gas. Generating electricity on site instead of building natural gas pipelines, can yield more efficient planning when based on economics only. Timing of shipments is significant and proposed new generation and transmission capacity, for a region, is planned using the best expected energy demand forecasts. Establishing therefore geographic boundaries, expected demands and proposed capacity expansions for a Middle East power pool will provide planners with a framework for an initial wide-market analysis on how much energy, type, when, and where shipments could most cost effectively flow.

2.2 Lower Reserve Requirements

Joint planning for utilities will increase generation diversity, thereby resulting in lower reserve requirements than individual separate planning. As individual generators represent a smaller fraction of the total system load, their unplanned outages are less likely to result in an overall generation shortage. While lower reserve requirements are a benefit of regional planning, the Purdue LT electricity trade models do not explicitly show this benefit. This benefit is determined outside of the model with the appropriate reserve requirement being placed into it..

The resulting regional wide reserve margin, which would be lower than the individual utility/national reserve margins, for the reasons stated, can then be used. The Purdue models trade in both reserves as well as energy (MW and MWh).

2.3 Load Diversity

Not all utilities/countries experience peak load conditions at the same time of day due to the different characteristics of the customers they serve. Similarly, they experience annual peak demand on different days. Therefore, the chronological sum of the individual utility loads provides a peak that is lower than the sum of the individual peak demands. Since generation capacity must be capable of handling the peak demand during the year, separate planning will result in larger generation requirements than will joint planning.

2.4 Economies of Scale

Generally, it requires less capital to construct one large facility than is required to build an equivalent capacity with several smaller units. Similarly, multiple units at a single site are cheaper to build than the same units at numerous different sites. These economies of scale result from common use of facilities, such as fuel handling, transformers, and transmission lines. Joint planning allows these economies to be captured more frequently than separate planning does by allowing utilities to share a jointly planned unit. There are substantial scale economies in hydro production, and substantial economic benefits in coordinating the operation of a combined hydro/fossil fuel generation system, where hydro is used during peak hours. This cuts down on the need for building expensive peaking combustion turbine units.

2.5 Joint Planning

This will allow a utility/country to utilize more generation options for both energy and capacity requirements within a larger market. A utility/country with little or no hydro sites available will not have to build a more expensive type of generation. Joint development of the transmission

networks increases the reliability of the system, allowing provinces/countries to use the collective capacity of the region to insure a reliable electricity supply, rather than each having to construct its own reserves, is another advantage of joint planning of trade in reserves. It has the same advantages as trade in energy.

Opportunities to use pumped storage on the supply side and integrated resource planning on the demand side to peak shave/valley fill until demand justifies construction of large dammed river hydro facilities are another advantage. In addition to reflecting the advantages of regional power pools, the Purdue LT models must take account of uncertainty regarding demand growth in the networks/countries of the region, as well as uncertainty on the supply side, with the impact of low rain falls in those countries that have hydropower, and lines or unit failures.

Long-run expansion decisions, 10 year horizons and more, must consider alternative growth and supply scenarios. An expansion plan based on most likely growth and supply scenarios may not be the preferred option, if its performance is measured against all scenarios. Flexible capacity expansion scenarios, ones where the cost of over, or under estimating demand/supply are not catastrophic to the region, are always preferred. An added feature of the LT model allows each network participant to decide on the maximum level of dependence on imports. It is expressed as an autonomy factor (number can be between 0 and 1) being domestic energy production capacity divided by peak demand, and depending on each country's level of need for security and autonomy.

An integrated energy grid allows increased movement of energy (electricity and natural gas) between countries and improves the national economies. Regional electricity markets can be of loose (limited bilateral trading) or tight power pool structure (free trade). Policy changes are assessed using mathematical and economic modeling that combines the generation and transmission facilities across a region while considering existing and proposed new expansions. Cost minimization techniques are typically used.

The Purdue models also address the problems currently facing deregulated United States power markets. How can it be insured that sufficient competition exists in electricity markets to prevent the exercise of market power by a few suppliers? The Purdue studies show that abuses can be expected in vulnerable regions of the grid during peak demand hours. Such behavior adds another dimension to the problem of network congestion caused by inadequate systems planning.

2.6 Energy Modeling & Planning at Purdue

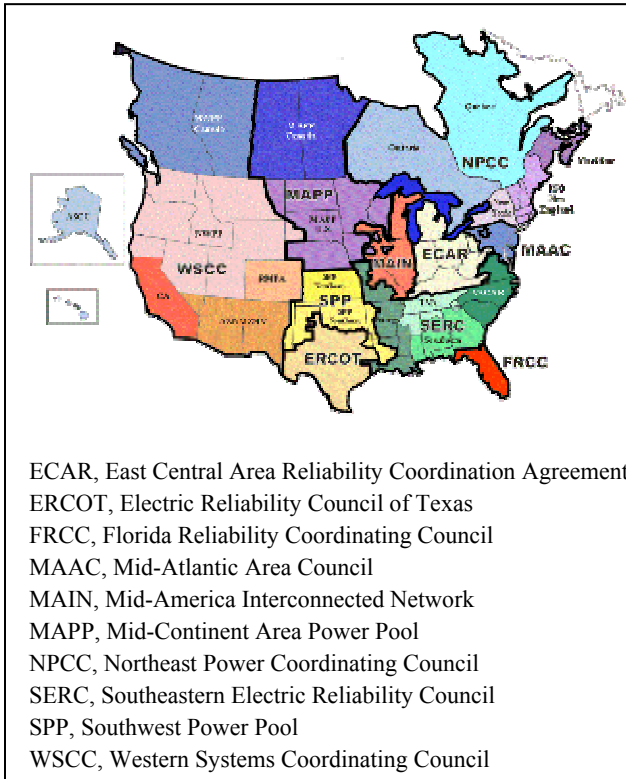
Purdue University's State Utility Forecasting Group (SUFG) has 20 years of experience in modeling electricity forecasts, analyzing alternative electricity trading arrangements, and strategic investment plans from working with the utilities and government regulatory commissions of the United States' Midwest. Also over the past several years there have been highly successful international partnerships with the 12 nations of the Southern African Power Pool (SAPP), and the newly formed West Africa Power Pool (WAPP). The Purdue models, combining economic, engineering, generation and transmission parameters, predict huge savings from a regional integration approach, for the SAPP, over 16 to 20 year planning horizons.

3. Energy Trade Analysis in the U.S.A. & SUFG Models

3.1 Electricity trading within the United States

North American electricity trading takes place under the structure of NERC (North American Electric Reliability Council). Regions of NERC are shown in Figure 1. Purdue's SUFG provides electricity forecasts and marketing analysis primarily for the State of Indiana and the ECAR, MAIN regions (Figure 1). New marketing studies are taking place for the Pacific North West, U.S.A., which is a section of the Western Systems Coordinating Council (WSCC). The total generating capacity of all 10 NERC regions was 639,000 MW in 1999 (43% coal, 19% natural gas, 15% nuclear, 13% hydropower and renewables, 8% petroleum).

Figure 1. Regions of the North American Reliability Council (NERC)



Electricity policy analysis publications are often employing models that are at a superficial level of detail with the spatial nature being all too often ignored. There are only a few user-friendly full-scale commercial quality network models available. The added usefulness from the Purdue economic models, above current commercial models, is that generation, and transmission, with regulation and deregulation scenarios, is catered for [2-6].

3.2 Purdue's current energy trade modeling systems

Purdue's SUFG has developed four major energy planning decision support tools:

- Traditional rate-based regulation models.
- 10-year forecasting model for Indiana and ECAR/MAIN under free competition.
- Short-run forecasting models for ECAR/MAIN peak hour prices.
- Up to 20-year forecasting for energy and reserve trade models.

The Purdue models are now described in more detail:-

(a) The traditional rate-based regulation modeling system, forecasts a set of representative hourly demand/supply equilibriums over a 20-year forecast horizon for Indiana electricity prices and outputs, based on prices covering variable costs plus a fair return on the rate base to investors. There is no network modeling in this model (see <http://www.fairway.ecn.purdue.edu/IIES/SUFG>).

(b) A 10-year forecasting system for Indiana and other states in the ECAR/MAIN reliability region, which assumes that electric generation prices are set competitively – e.g., hourly prices equal the cost of the most expensive unit dispatched to meet demand during the hour. Expansion is estimated based on proposed power projects. This is a “perfect” competition model with transmission constraints.

(c) A “snap-shot” short-run forecasting system that forecasts for select future peak hours electric generation prices in the ECAR/MAIN system if markets were deregulated, but suppliers were few enough to drive prices above marginal costs by withholding power during peak periods. Transmission constraints are also included [10].

(d) A 20-year forecasting system for energy and reserve trade between regions, which minimizes the present value of electricity generation costs, and generation/transmission capacity expansion costs subject to reserve constraints on the system. (This forecasting system has been used as a planning tool by both the Southern and West African Power Pools.)

The main advantages of the last modeling system are that it allows:

- Explicit optimization of generation and transmission capacity expansion.
- Consideration of reliability issues since trade in reserves to meet reserve requirement is explicitly considered.

3.3 The ECAR-MAIN & Midwest ISO Study

The 2001 study [3] for the ECAR-MAIN region of the U.S.A. indicated savings of the order of \$82 million over an eight year period (2004 to 2012) using an optimal location plan for new electricity power stations, compared with costs from plans initially drafted by the utilities.

Research at Purdue is now using modeling to forecast the impact on price and reliability in the ECAR/MAIN regions under various scenarios (Figure 2).

(i) It allows explicit consideration of the optimum extent and location of transmission investments as well as generation investments given a set of demand forecasts. (The others optimize only generation investments, and assume transmission capacity will be available, paid for by an "adder" to generation cost.)

(ii) Since reserve requirements are entered into the model as constraints on a region by region basis and are satisfied by the addition of reserve capacity (either constructed or purchased from others), the system can calculate the spatial impact on reliability of the least-cost transmission/generation expansion scenario.

With the latest legal structures of the ECAR-MAIN ISO (Independent System Operator) being established in 2001 there is an ever-increasing awareness for the need of improved regional planning, to give a broader perspective on generation and transmission expansion plans [7]. The Midwest ISO region consists of approximately 78,000 megawatts of generating capacity and more than 56,000 miles of transmission circuits with an installed investment of more than \$7 billion. Minimizing the cost of electricity supplies within the U.S.A., for the constantly increasing demand, continues to be a

major concern. New power plants are always therefore being considered for construction. The location of new power plants must now be considered within the larger regional ISO grid. The results of closer regional collaboration are being carefully being assessed within the ECAR MAIN region and across the whole U.S.A. This is very much still the case for several regions of the world. Quantitative analysis studies, of this nature, have an

important contributory role to play in energy market restructuring.

4. Energy Trade Analysis in the Southern African Development Community (SADC)

The Southern African Power Pool, SAPP, is a regional infrastructure of the Southern African Development Community (SADC). SAPP colleagues identified three main strengths of the Purdue modeling approach. These principal strengths are: (1) Involvement of users and having transparency and adaptability, (2) Designed for a particular problem - the simultaneous optimization of generation and transmission to meet projected demand within a very wide region, and (3) Cost effectiveness – a sophisticated model being made available at no cost to utilities/governments and the running of it requiring a modest investment in a high capacity PC installed with GAMS and cplex software [17].

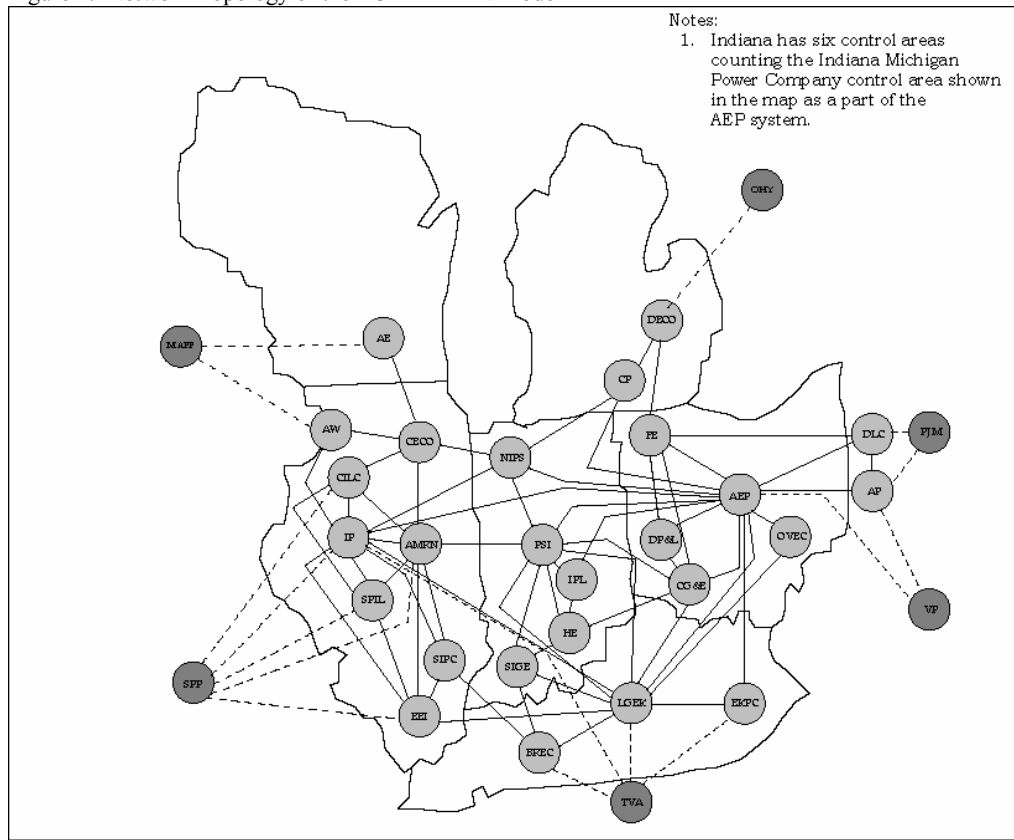
When considering a more flexible and free trade electricity trade policy in the Southern Africa region, the model demonstrated short-term savings of about \$70 to \$100 million per year, [5-8]. These savings are determined after significant operational and LT investment costs had been provided to Purdue from the utilities in the region. Adapting the model to a region requires a major initial data collection and data management procedures to be created.

The Purdue LT SAPP models showed savings of 13% when allowing full regional integration with electricity trade and generation capacity expansions over a 16 year planning horizon, compared with restricted trade practice of year 2000 levels.

The regional total costs amounted to \$13.1 billions for the period 2000 to 2016, indicating savings of \$1.7 billions from adapting a free trade policy and joint planning (Table 1).

Consistently robust aspects of the SAPP LT modeling results selected the Republic of South Africa's (RSA) new pumped storage, and the large coal fired refurbishment stations, both of the Angola hydro projects, and Cahorra Bassa North.

Figure 2. Network Topology of the ECAR-MAIN Model



ECAR-MAIN Key:

AEP (American Electric Power)
 AE (Alliant East) and AW (Alliant West)
 AMRN (Ameren)
 BREC (Big Rivers Electric Corp)
 CG&E (Cincinnati Gas & Electric Co.)
 and PSI (PSI Energy Inc.)
 CE (Commonwealth Edison Co.)
 CILC (Central Illinois Light Co.)
 CP (Consumers Energy)

AP (Allegheny Power)
 DLC (Duquesne Light Co.)
 DP&L (Dayton Power & Light Co.)
 EKPC (East Kentucky Power Coop.)
 FE (First Energy)
 HE (Hoosier Rural Electric Coop.)
 IP (Illinois Power Co.)
 IPL (Indianapolis Power & Light Co.)

DECO (Detroit Edison Co.)
 EEI (Electric Energy Inc.)
 LGEK (Louisville Gas & Electric + Kentucky Utilities Co.)
 NIPSCO (Northern Indiana Public Service Co.)
 OVEC (Ohio Valley Electric Corp.)
 SIGE (Southern Indiana Gas & Electric Co.)
 SIPC (Southern Illinois Power Coop.)
 SPIL (Springfield Illinois City Water, Light and Power).

Namibia's combined cycle and hydro projects, RSA's combustion turbine, Zambia's new hydro at Kafue Lower, Zimbabwe's new thermal station Gokwe North, and the initial expansion of transmission capacity along the Democratic Republic of Congo/Zambia/Zimbabwe/RSA spine were also consistently selected. These select new projects were then followed by later construction of the Democratic Republic of Congo/Angola/Namibia/Southern RSA new major transmission line, with other projects coming and going into the optimal solution. Expansions needed on these lines,

as well as the additional generation capacities (according to technology), are shown.

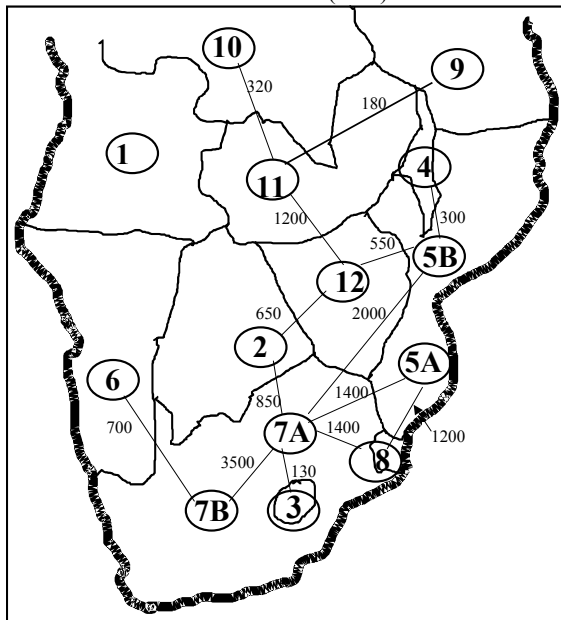
Figure 3 illustrates the existing major transmission network in the SADC in 2000 and in Figure 4 the expansions needed on these lines, as well as the additional generation capacities, are shown. The massive expansion of the DRC/Zambia /Zimbabwe /RSA transmission spine as well as the addition of the major new line down the west coast, DRC/Angola/Namibia/RSA are shown.

Table 1. SAPP Demonstration Total Costs
 (for 20 years is \$11.474 Billion)

Total Optimal Variable Costs for the Horizon	
Fuel	5.604
O&M	0.923
Water	0.419
Total	\$6.947bn
Total Optimal Expansion Costs for the Horizon	
Thermal	2.651
Hydro	1.187
Transmission	0.690
Unserviced Energy	0.000
Total	\$4.527bn

Demonstration results & not used for project evaluation

Figure 3. SAPP International Maximum Practical Transfer Capacities Existing or Committed for the Year 2000 (MW)



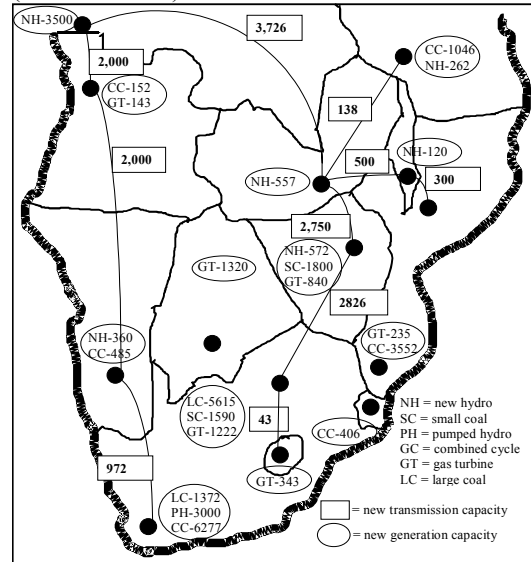
- 1. Angola (H)
 - 2. Botswana (T)
 - 3. Lesotho
 - 4. Malawi
 - 5A. S. Mozambique (H)
 - 5B. N. Mozambique
 - 6. Namibia (H, T)
 - 7A. N. South Africa (T)
 - 7B. S. South Africa
 - 8. Swaziland
 - 9. Tanzania (H, T)
 - 10. DR Congo
 - 11. Zambia (H)
 - 12. Zimbabwe (H, T)
- (H) = hydro site, (T) = thermal site

In 1999 the SAPP management decided on the establishment of its power pool coordination center to be located in Harare, Zimbabwe. This coordination center has taken more significance in the coordination of the SAPP with the initiation, in 2000, of daily electricity trading.

Besides the fixed LT bilateral electricity trade agreements between any two countries within the

Prices fluctuate from day to day and orders can be made 24 hours in advance for the purchase of wholesale electricity the following day. The Purdue LT model is now housed at the SAPP Harare coordination center.

Figure 4. SAPP Expansion Results of 20-Year Planning Horizon, Country Autonomy Constraint Relaxed (all units in MW)



5. Energy Trade Analysis in the Economic Community of West African States, ECOWAS

The Purdue modeling reports to the West African Power Pool, WAPP [2] shows repeated trends in the optimal expansion of the regional grid with specific new transmission lines having strategic value. Expected electricity demand growth scenarios have been employed as well as low demand growth scenarios. Major gains, as much as 13% savings in total costs, are made in West Africa from a regionally integrated free trade electricity policy compared with limited or no energy trade among the ECOWAS states. For the past 10 to 15 years ECOWAS has concentrated its' attention on the need for a regional electricity power grid. Modeling attention has been given to new international transmission lines and the modeling is showing this to be a highly cost effective plan.

With a WAPP free trade scenario the total cost of new lines and expansions on existing transmission lines amounts to only 4.7% of the total capital expenditure (or 1.6% of total regional cost). This \$275 million (\$100 million to existing lines

expansion and \$175 million to new lines expansions) for lines capital expenditure provides a very attractive investment basis for making substantial regional savings to the order of \$4.5 billion (\$21 billion – \$16.5 billion) across the region for the 20-year LT horizon.

In the ECOWAS Zone A of WAPP (the eastern part of the region which is the more developed of the two zones) over 2000MW of new load carrying capability is added to the two lines, Benin to Togo, and Togo to Ghana. The largest expansion in ECOWAS Zone B of WAPP (western part of the region) is from Cote D'Ivoire to Guinea with a total LT expansion of 442MW. The second largest expansion in Zone B is between Guinea and Senegal, with 365MW. The total regional lines expansion, with free trade, is 474% (3840MW total compared with 810MW) greater than with national autonomy across the region for the 20 year planning horizon. Figure 5 shows the more likely lines expansion plan with a low demand growth scenario.

In September 2000 the WAPP was officially launched by the government energy ministers of ECOWAS. The Purdue modeling work for WAPP had started a year earlier. Purdue's policy and capacity expansion analysis work, and particularly its' regional data collection and training activities have certainly contributed to the process of building up WAPP infrastructure and its' policy formulation.

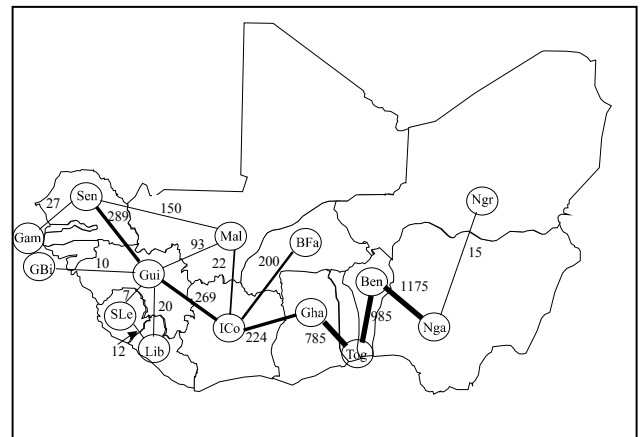
For the 20-year horizon Nigeria is a net exporter of 152TWh in order to achieve minimum regional costs for the 20-year horizon. Benin and Togo become major wheelers of electricity to Ghana and the rest of the region. Guinea becomes an important center of regional electricity trade for the ECOWAS Zone B.

Purdue's WAPP modeling work helped to accelerate the formation of the WAPP in 2000 and also to develop a forum for promoting economically sound regional policy while also attracting more attention from international agencies and investors. Purdue is scheduled to work with the ECOWAS Secretariat through 2003.

The WAPP is an example of a young loosely structured power pool.

The SAPP with its' daily trade market is becoming more flexible with the growing operational significance of its' coordinating center in Zimbabwe. An outstanding example of one of the most structured and tightly integrated power pool currently being operated, is the Nord Power Pool. It is an impressive, efficient and tightly structured pool and is another example for consideration in the development regional power pools (Appendix).

Figure 5. Total ECOWAS International Transmission Demonstration Capacities for 2020 Assuming a Low Electricity Demand Growth & Free Trade Expansions (MW)



Line Name	Load Carrying Capacity in 2000 (MW)
(1) Ben-Tog	150
(2) BFa-ICo	200
(3) Gha-Tog	256
(4) Gha-ICO	327
(5) Mal-Sen	150
(6) Ngr-Nga	70

ECOWAS Country Notation:

Ben – Benin	BFa – Burkina Faso	ICo – Cote D'Ivoire
Gam – Gambia	Gha – Ghana	Gui – Guinea
Gbi – Guinea Bissau	Lib – Liberia	Mal – Mali
Nga – Nigeria	Ngr – Niger	Sen – Senegal
SLe – Sierra Leone	Tog - Togo	

6. South Asia Electricity Capacity Planning

The past 10 years have seen enormous increases in demand for electricity in the South Asia region. The region is chronically short of electricity and investment by Independent Power Producers (IPPs) is now a top policy priority for the region in the planning for increased capacity. Incredibly high annual electricity demand growth rates are forecast by the respective government energy departments.

Nepal's annual electricity demand growth rate, for example, is forecast to be 14% to 15% [15]. Sri Lanka's annual demand growth rate is estimated at 8% [14]. Integrated power pooling can help to cut the running and capital costs for South Asia in the attempts to meet these very high demand growth rates.

The dominant player in a South Asia electricity market is India with its existing 112GW of generating capacity (Table 2). Cost savings to India can be substantial by importing cheap hydropower from Nepal and Bhutan while providing major export revenues to these two latter countries. Whether to import natural gas from Bangladesh or to import electricity are important policy and infrastructure issues for the region. In 2000 India accounted for 86% of regional electricity generation with Pakistan 10%, Bangladesh 2%, Sri Lanka 1% and Nepal, Bhutan, and the Maldives 1% [13].

Table 2. Existing Generation Capacity in Southern Asia

	Total Generation Capacity (MW)	Percentage thermal generation	Percentage hydropower generation
Bangladesh	3,600	94% 68% nat.gas	6%
Bhutan	355	-	99%
India	112,000	74% 53% coal	22%
Maldives	25	100% petroleum	-
Nepal	347	13%	87%
Pakistan	18,000	86% 45% nat.gas 41% petrol	12%
Sri Lanka	1,779	37% petroleum	62%
TOTAL	136,449		

Table 2 also shows the mix of generation technologies in South Asia. Commercial energy consumption in Bangladesh involves 68% natural gas. With significant natural gas resources (16Tcf of net recoverable reserves cf. China 48Tcf & USA 167Tcf) Bangladesh is still experiencing severe damage to its economy, in the order of \$1 billion per year according to the World Bank, due to energy shortages and unreliable supplies [11]. Losses in the Bangladesh electricity industry are as high as 40%. The Government of India is planning for generating capacity increases of 47,000MW for the present 5-Year Plan and 107,000MW extra for

2007 which will use both coal and natural gas technologies [12]. South Asia faces the problem of rural electrification. The densely populated urban areas are electrified but the decision on appropriate technology rural electricity connections is a challenge from any economic perspective. Only three out of the seven countries of the region have more than 50% of their populations having access to electricity (Table 3). The annual kWh production is low by international standards. India and Pakistan have similar orders of magnitude of kWh per capita (525, 481) but these are only a fraction of the electricity intensity of the more industrialized countries (Table 3).

Table 3. South Asia's Populations & Electricity Production

	*Population in 2001 (millions)	* Population % access to electricity	kWh production per capita in 2000
Bangladesh	133.3	20	118
Bhutan	2.0	-	-
India	1,032.4	80 ⁺	525
Maldives	0.3	-	333
Nepal	23.6	15	72
Pakistan	141.5	52	481
Sri Lanka	18.7	62	363
<i>Lesotho</i>	2.1	5	-
<i>South Africa</i>	43.2	66	4,810
<i>Ghana</i>	19.7	45	365
<i>USA</i>	285.3	99	14 ,032

Source: * [16], + [12]

Planning of international and national transmission lines will need special consideration from an economic perspective. The new international transmission lines will be essential in the forming of the regional pool and some of these major new projects are shown in dotted lines in Figure 1. Transmission and distribution within each country are each major planning issues. Building of these new lines is shown by the Purdue models to be very cost effective. Significant losses are reported by most of the countries of the region. Nepal transmission line losses are reported, by the Nepal Electricity Authority (NEA), to be 27% in rural areas [13]. The new international lines will take high priority in the early stages of developing a South Asia power pool.

7. South Asia Economic Power Pool Models

The Purdue electricity economic models, proposed for the region, will give support to the development

of several key planning areas for the new power pool. The support will include:

- Trade policy analysis. Assessing bilateral and flexible trading arrangements. Comparing fixed trading with free trading plans.
- Provision of estimates of the benefits from alternative electricity trading arrangements of trading energy (MWh) and trading reserves (MW).
- Showing the gains from trade for each country in the power pool.
- Promoting the essential need of developing a regional data management system from which the South Asia regional model can be built.
- Giving an insight for investors into the most cost effective projects for the region.
- Assisting national energy planners in prioritizing electricity capacity expansion projects.
- Giving a framework of policy analysis to national and regional regulatory agencies.

Well documented initiatives for the region are listed in Table 4. Over the next decade clearly tens of billions of investment dollars are required for developing the South Asia electricity infrastructure.

Table 4. Major Regional Capacity Expansion Projects

Country	Name of project	Capital cost (\$ millions)
Bangladesh	Power System Master Plan, PSMP	4,400
Bangladesh	150MW international transmission to India	-
India	Unification of the national power grid	-
India	Hirma coal-fired station, 3,960MW	5,000
India	Enmore LNG station 1,886MW & LNG import terminal	-
Bhutan	6,000MW to 20,000MW hydropower potential	-
Nepal	83,000MW hydropower potential	-
Sri Lanka	10 Year Development Plan with \$1bn for generation & \$1.5 for lines	2,500

Collaborative modeling activities for a South Asia Power Pool (SASIAPP) can be an excellent and effective means of developing the infrastructure and policy analysis for a new power pool. This has been the experience of the Purdue modeling team with its' 20 years of electricity modeling experience in North America, Southern Africa and presently

also in West Africa. This will require government energy policy managers, modelers, academics, and utility experts from each of the seven countries to coordinate regional electricity planning summit meetings. The model shown in Figure 1 can be a starting point from which to consider the structures for the SASIAPP. In Figure 1 India has been given nodes 1 to 5 to express its large geographic scope. As the regional electricity models are built then further nodes can be added with nodes for example representing East Bangladesh and a further node representing West Bangladesh. Initial models for this regionally integrating work can operate readily on laptop computers with the appropriate installation of mathematical solvers. This Dhaka, July 2003, meeting might be a significant landmark in the creation of the South Asia cooperative electricity modeling project.

References

- [1] F.T. Sparrow, Brian H. Bowen, "Transferring the SAPP Electricity Planning Methodology to SAPP High Level Utility Planners", SAPP Management Conference Consultations, Windhoek, Namibia, February 20-22, 2001.
- [2] F.T. Sparrow, Brian H. Bowen, Diakalia Sanogo, "Input & Output Parameters in the West Africa Power Pool Long-Term Model", ECOWAS WAPP Project Implementation Committee Conference, Cotonou, Benin, September 17-21, 2001.
- [3] F.J. Smardo, "Spatial Subsidies Under Competition Within the ECAR-MAIN Power System," MS Thesis, School of Industrial Engineering, Purdue University, December 2001.
- [4] Z. Yu, F.T. Sparrow, D. Gotham, F. Holland, D. Nderitu, "The Impact of Transmission on Imperfect Competition," Proceedings of IEEE PES Winter Meeting, 2002.
- [5] Zuwei Yu, F.T. Sparrow, Brian H. Bowen, "Pooling Resources In Southern Africa", TRANSMISSION & DISTRIBUTION, February 2001, pp 58-68.
- [6] Brian H. Bowen and F.T. Sparrow, "Regional Hydropower Policy and Capacity Expansion Modeling for the Countries of Southern Africa," INTERNATIONAL WATER POWER & DAM CONSTRUCTION, February 2001, pp 16-21.
- [7] F.T.Sparrow, Brian H. Bowen, Zuwei Yu, "Modeling Long-Term Capacity Expansion Options for the Southern African Power Pool (SAPP)", Proceedings of the IASTED International Conference, Power and Energy Systems, Las Vegas, Nevada, November 8-10, 1999.

- [8] Brian H. Bowen, F.T. Sparrow, Zuwei Yu, "Modeling Electricity Trade for the Twelve Nations of the Southern African Power Pool (SAPP)", UTILITIES POLICY 8, 1999, pp 183-197.
- [9] Zuwei Yu, F.T.Sparrow, Brian H. Bowen, "A New Long Term Hydro Production Scheduling Method for Maximizing the Profit of Hydroelectric Systems", IEEE TRANSACTIONS on Power Systems, Volume 13, Number 1, February 1998.
- [10] Z. Yu, F.T. Sparrow, D. Nderitu, D. Gotham, F. Holland, T. Morin, "A Large Spatial Gaming Model for the Midwest Electric Markets," Proceedings of IEEE PES Summer Meeting, 2001.
- [11] Bangladesh Country Analysis Report, EIA, DOE, February 2003.
<http://www.eia.doe.gov/emeu/cabs/bangladesh2.html>
- [12] India Country Analysis Report, EIA, DOE, January 2002.
<http://www.eia.doe.gov/emeu/cabs/india.html>
- [13] South Asia Regional Country Analysis Brief.
<http://www.eia.doe.gov/emeu/cabs/sasia.html>
- [d-14] Power Market in Sri Lanka,
http://www.tradepartners.gov.uk/energy/sri_lanka/profile/overview.shtml
- [15] Himalayan Light Foundation,
<http://www.hlf.org.np/energyintro.htm>
- [16] World Development Indicators, World .Bank, 2003, p.152
- [17] GAMS; The Solver Manual, GAMS Development Corporation, Washington DC, USA.

Appendix

The Nord Pool is the marketplace for trading electric power in the Nordic countries (Sweden, Norway, Denmark, and Finland). Nord Pool, or the Nordic Power Exchange, is a multinational commodity exchange for electric power. Established in 1993, Nord Pool is owned by the two national grid companies, Statnett SF in Norway (50%) and Svenska Kraftnät in Sweden (50%). In Finland, Nord Pool is represented by the Finnish power exchange EL-EX in Helsinki. Nord Pool very actively participates in the development of exchange trading of electric power in Europe's deregulated power markets. At present the Nord Pool would not be a suitable structure for the Mid-West USA, and probably it is not the most suitable structure for the GCC but the power planners have

extremely valuable lessons to learn from this impressive energy market structure.

Biography

Brian H. Bowen is associate director of the Power Pool Development Group, PPDG, at Purdue University, where he received his Ph.D. in industrial engineering. Before his association with Purdue he worked in West Africa and Southern Africa for 15 years in engineering education and energy. His research interests are in power pool development, energy trade modeling, and engineering in economic development.

F.T. Sparrow has been professor of industrial engineering and economics at Purdue University since 1978. He has a Ph.D. in economics and operations research from the University of Michigan. He is director of the Purdue State Utility Forecasting Group (SUFUG) and the Power Pool Development Group (PPDG) with his interdisciplinary interests focusing on energy modeling and analysis. Honored as a Ford Foundation research professor, his is also a consultant to various agencies and utilities.

Zuwei Yu is an associate professor of courtesy appointment and senior analyst with the State Utility Forecasting Group (SUFUG) at Purdue University, which he joined in 1996. He has a Ph.D. in electricity engineering from the University of Oklahoma. He has extensive experience in electricity market modeling for different markets around the world and is the chief modeler for SUFG studies on electricity industry restructuring for Indiana and natural gas modeling.