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Modeling Long-Term Capacity Expansion Options for the Southern African Power Pool (SAPP)

Long-term planning for the expansion of capacity in transmission and generation demands the attention of electricity utilities in both the highly industrialized regions and the less industrialized regions of the world. While utilities in the developed nations have long recognized the need for regional, rather than local planning, primarily for reliability purposes, utilities in less developed nations are rapidly catching up, as the reliability and economic benefits of joint construction and utilization planning overcome perceived national needs for country autonomy.

This policy brief addresses two major policy issues associated with such regional, rather than local approaches:

• Should individual nations give up some measure of autonomy and electricity self-sufficiency in order to achieve lower cost electricity? How should nations approach this decision to either "make or buy" electricity?

• How should the extraordinary uncertainty surrounding the national electricity demand growth trajectories of SAPP members enter into these decisions?

Purdue University's State Utility Forecasting Group (SUFG), in collaboration with utility staff in the Southern African nations, has developed a mixed integer cost minimizing optimization model for the Southern Africa Power Pool (SAPP). This is to help SAPP develop least cost expansion and utilization plans, enabling members to assess the benefits of such joint planning. From 1997 until the present, this modeling activity, funded by USAID, has involved collaborative

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research and data collection between researchers at Purdue and the engineers and managers of the twelve national electricity utilities of the Southern Africa Region.

Details of the formulation that form the model are available from earlier SUFG publications [1-10]. The model minimizes the total expansion and production costs in an integrated manner, which includes transmission. The inclusion of transmission constraints in the expansion model is particularly important, since shortages in transmission capacity have been hindering the substitution of clean, cheap hydropower from the north for the more expensive, polluting thermal power in the south of the region.

The long-term model is a mixed integer mathematical program which, using the GAMS and CPLEX solver software, minimizes the present value of total costs (capital, fuel, operational and maintenance, and unserved energy) for SAPP over a user specified time horizon, subject to a set of constraints. The constraints include:

- Supply/demand equations, which insure that user specified demands are met for each hour modeled for each of the day types in each of the seasons;
- Capacity constraints, which insure that each plant's generation does not exceed current rated capacity;
- Reliability constraints, which insure that a proper reserve margin is maintained between installed or purchased capacity and peak demand;
- Country autonomy constraints, which insure that domestic capacity is always greater than a pre-determined fraction of domestic peak demand.

Three commodities are traded in the model:

a) Spot power to meet demand, obtained in the open market, with no guarantee of availability;

b) Firm power to meet demand, available up to a prescribed maximum guaranteed by the seller;

c) Firm capacity, which the buyer may use to satisfy reserve requirements, and which sets the upper limit on firm power imports.

The model contains more than 600 integer variables, which model the fixed costs of capacity expansion of the construction options (large coal, small coal, combined cycle, hydro, pumped hydro, AC & DC transmission lines). The model also contains 500,000 continuous variables representing such operating and maintenance costs for the available units for each hour, day, season, and year modeled and 20,000 constraints of the types described above.

The model can be run on a personal computer with the following specifications:

Pentium II BX 100 MHz motherboard

Pentium II 350 MHz processor

512 Mb 100 MHz RAM

9.61 Gb UWSCSI hard drive.

Typical run times vary from minutes to hours, depending on the number of declared binary and integer variables,

horizons length, and knowledge of a good upper bound on the cost minimizing solution to the problem. The model can also be run in a UNIX environment.

The model software and operating instructions are non proprietary. Copies can be obtained by e-mail: clallen@ecn.purdue.edu, phone: (765) 494-7036, or fax: (765) 494-2351. The data provided by SAPP is, however, proprietary.

Recent work completed in the last few months, not included in our discussion paper, casts the policy issues in a different light than previously described. Recent results show that:

• The cost of self-sufficiency in electricity supply is substantial. If each country requires that it maintain enough domestic capacity to satisfy its own electricity reserve requirements, rather than allowing reserve requirements to be met at least cost by SAPP collective action, the SAPP-wide construction budget over the planning horizons almost doubles.

• Trade between SAPP members is still substantial with the self-sufficiency constraints in place. Even with the construction of capacity held in reserve for protection from import interruptions, it is still cheaper to import low marginal cost power from the operation of others' idle reserves than to operate higher marginal cost domestic reserve power plants.

• Trade constraints that require a certain fraction of a country's power requirements to be met by operation of domestic generation plants would impose even harsher economic penalties on the region.

• Regional approaches to capacity expansion planning should carefully examine the impact of demand forecast error on their plans. Initial results indicate that if the cost of over-forecasting demand, resulting in expensive project cancellations, is greater than the cost of under-forecasting demand, resulting in relatively less expensive additions of capacity with short construction lead times (gas turbines, combined cycle plants), SAPP should design its capacity expansion plan for its low growth scenario, not its expected growth scenario.

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