

**CAPACITY PLANNING IN A TRANSITIONAL ECONOMY:  
WHAT ISSUES? WHICH MODELS?\*****Vinod Mubayi**Department of Advanced Technology  
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**ABSTRACT**

Electric capacity expansion models were developed in the 1950s to provide system planners with a tool to guide investment decisions in new generation capacity needed to meet growing loads on an interconnected system. The models utilized the techniques of the then new science of decision theory, linear programming (LP), later augmented by integer and mixed integer programming, dynamic programming and reliability analysis. The objective was to find, over the planning horizon, the minimum discounted net present value of investment over time in new candidate generation alternatives required to meet future demand subject to various constraints and reliability (loss-of-load-probability) considerations. A good example of such models is the WASP (Wien Automated Systems Planning) model (I.A.E.A., 1973) developed under the auspices of the International Atomic Energy Agency originally to forecast the possible demand for nuclear power plants in several countries within the boundaries of an optimal capacity expansion plan. To augment the temporal aspect of expansion planning, models were later developed to focus on the spatial dimensions of power system planning, including investments in transmission system upgrading, explore plant locational issues such as the mine-mouth vs. load center trade-offs, and to incorporate environmental constraints on power plant siting. Seminal approaches to deal with some of these issues were, in fact, developed in the former Soviet Union (Makarova, 1966) which operated a very large interconnected power system.

Historically, capacity expansion planning developed in the U.S. and Western Europe in a climate characterized by a stable regulatory and financial environment, a predictable and fairly constant growth of demand for electric energy (approximately 7% per year in the U.S. in the 1950s and 1960s) and a stable cost of capital. The situation that currently obtains in Russia is vastly different; a transitional economy, characterized, at least in the short term, by a steeply falling demand for electric energy, large uncertainties in the

cost of investment capital and an evolving regulatory framework where basic questions of ownership, responsibility, and a rate of return on assets are still being addressed.

This paper is devoted to an exploration of the important issues facing the Russian power generation system and its evolution in the foreseeable future and the kinds of modeling approaches that capture those issues. These issues include, for example, (1) trade-offs between investments in upgrading and refurbishment of existing thermal (fossil-fired) capacity and safety enhancements in existing nuclear capacity versus investment in new capacity, (2) trade-offs between investment in completing unfinished (under construction) projects based on their original design versus investment in new capacity with improved design, (3) incorporation of demand-side management options (investments in enhancing end-use efficiency, for example) within the planning framework, (4) consideration of the spatial dimensions of system planning including investments in upgrading electric transmission networks or fuel shipment networks and incorporating hydroelectric generation, (5) incorporation of environmental constraints and (6) assessment of uncertainty and evaluation of downside risk. Models for exploring these issues include low power shutdown (LPS) which are computationally very efficient, though approximate, and can be used to perform extensive sensitivity analyses to more complex models which can provide more detailed answers but are computationally cumbersome and can only deal with limited issues. The paper discusses which models can usefully treat a wide range of issues within the priorities facing decision makers in the Russian power sector and integrate the results with investment decisions in the wider economy.

**1. SUMMARY OF FINDINGS**

The electric sector planning situation in Russia is unique as a result of the vast size and inter-connectedness of the system and the confluence of circumstances which will lead to significant decreases in load in the near future, followed at some point by the reestablishment of more or less robust growth. Also, the presence of both nuclear plants of uncertain reliability and aging fossil plants

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of (currently) certain and excessive emissions characteristics results in many plausible scenarios for the system which will serve this load. In sum, the level of uncertainty is unique and requires planning methods and models which are flexible, detailed and sensitive to parametric variations.

We reviewed available models and found necessary ingredients in most modelling systems; none were sufficient in themselves, so model integration by intelligent analysts remains the single most important tool. Reliability-oriented models capable of modelling on the level of individual generating plants are a necessary first step in the process and will establish optimal generation mixes. Models should be chosen which can optimize under environmental emissions constraints and while taking potential emissions taxes into account. Spatial questions such as power transmission/mine mouth siting questions cannot be settled by these models, however, and require the use of linear programming models in which the multi-area nature of electric utility systems can be expressed adequately. Finally, questions such as future Russian fuel mix changes cannot be predicted or assessed using any model restricted to the electric sector, and we briefly discuss the importance of linkages to broader energy sector models.

In the last section we illustrate and emphasize the importance of downside risk assessment: in an electric sector as dominated by uncertainty as Russia's, it is critical that the choice of optimal development paths hinge not only on which path promises the lowest discounted total cost, but on which path will prove the least costly if the assumptions on which it is based turn out to be false. Successful execution of this program requires that the models to be used be capable of rapid and organized comparison of many scenarios based on significantly different assumptions. Such tools, used flexibly and creatively are required to plan the power sector effectively in Russia's road to economic recovery.

## **2. ISSUES FACING RUSSIA'S POWER SECTOR**

Russia operates one of the world's largest integrated power systems, the second largest in capacity, after the U.S., and the largest in terms of spatial extent. Excluding the Far East system, which is operated separately, the unified power system of Russia spans six time zones and extends over a distance of 9000 km from east to west. The Russian system is part of the interconnected grid of the former Soviet Union; many of the bulk transmission lines which transfer large blocks of power among the regional grids of Russia pass through territories which now comprise independent countries. Total installed capacity is around 190 GW consisting of about 130 GW thermal (coal and lignite, natural gas and fuel oil fired), 41 GW hydro, and 20 GW nuclear. The thermal plants include several combined heat and power plants which supply district heat to their service areas. The total generation in 1993 was about 850 billion kW h. Electric energy consumption among the 7 regional grids comprising the Russian power system is follows: Center 29%, Urals 25%, Siberia 19%, Middle Volga 10%, North West 7%, North Caucasus 6%, and the Far East 4%. The regional grids are connected through undertows at levels of 330 k. and above up to 1150 k. AC and 1500 k. DC. Due to historical reasons, the power systems of the newly independent countries, Kazakhstan, Ukraine, Belarus, south Caucasus states (Armenia, Azerbaijan, Georgia), the Baltic states (Estonia, Latvia, Lithuania) and the middle Asian states (Kirghizia, Turkmenistan, Uzbekistan) are in synchronous operation with the Russian unified power system. Upgrades to the bulk transmission capacities and trade-offs between

new capacity versus strengthening of transmission links are not just technical and economic issues; there are also political dimensions involved.

The scope and extent of the power planning problem in Russia, i.e., the provision of economic and reliable service in a safe, environmentally sound manner, can be described in terms of the following key issues:

### **2.1 Electric Demand**

The accurate projection of future demand, as characterized by the magnitude of the peak demand and the shape of the load curve, is a key requirement of capacity planning. Economic growth in Russia has been negative since the late 1980s. By late 1993, economic output in Russia as measured by the Gross National Product (GNP) had fallen to about 62% of its level in 1990. A further decline in GNP was experienced in 1994 and is projected to occur in 1995. Electricity consumption has also declined but at a slower rate than the economy. Electric consumption in 1993 was at 87% of its level in 1990 and is projected to fall further to about 80% of its 1990 level in 1995. In the recent Joint Energy Alternatives Study (JEAS, 1995) undertaken cooperatively by Russian and U.S. agencies two scenarios of future economic development were projected along with corresponding projections of electric demand. In the first (optimistic) scenario, the economic decline stops in 1996, followed by recovery beginning in 1997. The GNP recovers its 1990 level by 2003-04 and then grows steadily at between 3% and 4% per year until 2010, the time horizon of the study. In the less optimistic scenario, the economy continues to fall till 1998, and then stagnates before recovering to 70% of its 1990 level in 2010. Electric energy demand is projected along both of these scenarios in a lagged fashion. In the optimistic scenario, electricity demand increases 20% over the 1990 level by 2010; in the other scenario energy demand just recovers its 1990 level by 2010.

Since the decline in electric energy consumption is lagging the decline in GNP, the electric energy intensity with respect to GNP (ratio of the percent change in electric energy consumption to percent change in GNP) is actually worsening in Russia, in sharp contrast to the situation in most OECD countries which have significantly improved the energy efficiency of their economies over the last two decades. A large portion of this situation can be ascribed to the predominance of heavy industry in the final energy consumption pattern. Many of these industries are now contributing little to economic output but have been kept operating due to social reasons. Heavy industry accounted for over three-fifths (61%) of electric energy consumption in 1991 and had only fallen to 58% of the total in 1993, while the residential and commercial share was only about 20% in 1991. Loss of economic output accelerated by the closure of many heavy industries is bound to affect the shape of the future system load curve which should become more peaky as the residential and commercial share of consumption rises.

There are significant opportunities for energy conservation and energy efficiency upgrades in all sectors of the economy especially in industry. The JEAS identified 57 efficient technologies ranging from higher efficiency motors to compact fluorescent lamps which could reduce projected consumption by 35-40% in the year 2010 and could be installed in a cost effective manner (at a cost equivalent to less than U.S. \$0.04/kW h saved). The implementation of energy efficient technologies can, in principle, significantly affect future demand for electric energy due to its large potential in Russia. Because of the extreme shortage of capital and the lack of price signals, it is difficult to predict the extent and rate of penetration of

conservation technologies, but because energy efficiency technologies are commonly end-user technologies and require the accumulation of much smaller parcels of capital than do power plants, they may play a key role well before major new construction projects are again undertaken. Ability to model the impact of energy efficiency technologies is a key requirement for electric sector planning in the Russian environment.

Perhaps the most significant aspect of the future trends in energy demand and the economic forecasts by which they are driven is their uncertainty. Modeling approaches should be able to incorporate these uncertainties. In particular, it would be highly desirable to have a linkage between broader representations of the energy economy and the electricity consumption sectors to allow for consistency in forecasting trends in the economy and in energy consumption. Such linkages are discussed in section 5 below.

## **2.2 Spatial Aspects of Planning**

In spatially large systems the presence of diversity (non-coincidence of system peaks) lends considerable rationale to their interconnection; the peak of the interconnected system is less than the sum of the individual peaks which lowers the generation capacity required to meet demand at the same reliability. In the Russian power system, this factor plays an important role since the various grids are located in different time zones. Additional investment in transmission capacity between the Siberian and Center regions and in technologies for better control of load dispatch and scheduling were identified in the JEAS.

Over the longer term, other areas of spatial planning in the Russian power system may need to be investigated. These include, for example, the so-called mine-mouth versus load center power plant siting problem. The issue here is the trade-off between transportation of fuel, including investment in additional transport capacity, to plants located in the vicinity of load centers versus augmentation of bulk transmission capacity to permit plant siting at the fuel source. This issue can become important if environmental constraints on siting coal fired capacity in urban areas are strictly enforced for future plants.

Investment in new hydro capacity located in remote areas (for which the Siberian regional system affords a number of examples) is a classic spatial programming problem where transmission losses have to be carefully considered. Case studies of individual plants were carried out in the JEAS. While these have generated valuable data, they need to be explored in the context of an overall system plan to ensure that the choices offered are indeed optimal.

## **2.3 Safety Enhancements to Nuclear Plants**

Russia operates about 20 GW of nuclear capacity of various types including graphite-moderated reactors (RBMKs) and pressurized water reactors of different vintage. There are also several unfinished nuclear power plants in various stages of construction. Concern about safety, especially in the aftermath of Chernobyl, led to a program of identification of safety upgrades at the various plants. The investment choice problem is to (a) complete the safety enhancements at the older, operating plants to decrease their risk or decommission them before their normal end-of-life, and (b) repower partially completed plants as fossil plants or complete them as nuclear units with safety upgrades. Costs of these various options were studied in the Joint Parallel Nuclear Alternatives Study for Russia (JNPAS) by a Russian-U.S. team as part of the JEAS.

## **2.4 Refurbishment of Thermal Plants**

Over half (78 GW) of Russia's thermal plant capacity is expected to reach the end of its design life within the next 15 years. Due to the decline in demand, the retirement of aging plants has not had a significant impact on system reliability yet, but this situation may not obtain in the future. Future investment choices for replacing the retired capacity include: life extensions of current plants with perhaps fuel switching in specific cases (replacing coal boilers by natural gas boilers, for example), replacement by new, higher efficiency plants such as combined cycle plants, retrofitting environmental control technologies on the older plants to be modernized, etc. Russia has adopted emission standards for particulates, NO<sub>x</sub>, and SO<sub>x</sub> which are comparable to Western European standards. New or refurbished capacity will have to meet these standards which are not met by current plants. The choices need to be adequately represented within the capacity planning model along with the nuclear capacity choices.

## **2.5 Energy Exports vs. Domestic Use**

Export of energy resources, mainly natural gas, is one of the chief hard currency earners for Russia. There can, in principle, be a choice problem between greater use of gas in the power sector versus export though this may not be important within the next decade due to the ample gas reserves.

## **2.6 Economic/Financial Evaluation**

Finally, the choice of a discount rate, a rate of return, or other figure of merit to evaluate the ranking of investments, is highly uncertain in the current financial climate in Russia. Thus any model approach must be able to accommodate a large number of runs with different assumptions.

# **3. RELIABILITY-ORIENTED GENERATION PLANNING MODELS**

Electric utility planning incorporates an assessment of the reliability of all possible future configurations of the generation system. All models in use today incorporate some method for assuring that the probability that the system will be unable to meet load is less than some small, specified value.

## **3.1 Measures of System Reliability**

Incorporating component reliability into generation system planning involves the convolution of the reliability of individual generation units to give a reliability for the system as a whole. Each individual plant is characterized by an "availability," a fraction which indicates what percentage of the time the unit can be expected to be available when it is called on. Scheduled outages are normally accounted for separately. Through redundancy, the reliability of the system is always higher than that of the individual units of which it is comprised. The overall system is more commonly characterized by the reverse measure, the "loss of load probability" (LOLP), which is the fraction of the year that the load on the system is expected to exceed available capacity.

Because all generation units have some (non-zero) probability of outage, however, the loss of load probability can only approach zero; there is always a finite chance that available units will not be available to meet the full load. The energy which careful planning indicates will not be available when customers demand it is called "unserved energy." Only rarely is it truly unserved; normally these

loads are met with emergency purchases, but "unserved energy" serves as the second common measure of system reliability.

The third and much cruder measure of system reliability is the "reserve margin" of the system at any time. This is simply the margin by which the capacity of currently available units exceeds current demand. Assuring that available capacity will be greater than peak demand by some specified figure, for example, 20% is taken as a rule-of-thumb indication that reserves are adequate. (Current Russian planning operates with a reserve margin of 13%). This approach does not differentiate between the case when a modestly sized system includes a single large plant which could cut its reserve margin in half were it to fail, and a more robust system where all units contribute comparable, modest capacity.

All three of these criteria are used to assure that planned systems will perform with adequate reliability, but calculation of the LOLP and unserved energy is normally required before serious planning decisions are made. The models used to calculate them are of two sorts: multiple hourly simulation models and models using Baleriaux-Booth probabilistic dispatch.

### **3.2 Hourly Simulation Models**

Hourly simulation models are the tool of choice for American utilities. They are detailed simulations, hourly over a twenty to thirty year study period, bringing in variable heat rates, seasonal variations in outage probabilities, scheduled maintenance and many other technical details. In some cases they employ a "Monte Carlo" technique (Hall, 1968) to represent outages, where the same simulation is repeated many times, with a random number generator deciding which units will unexpectedly drop out of service. In other cases, the exact methods are proprietary. Simulation of systems incorporating all candidate new units allows system optimization, the choice of the least expensive system meeting load with the specified level of reliability. Use of these models produces great confidence among U.S. utility planners, but can cost \$100,000 per year.

### **3.3 Probabilistic Dispatch Models**

Baleriaux-Booth ("BB") probabilistic dispatch (Baleriaux, 1967; Booth, 1972) is based on manipulation of the load curve so that each plant sees a load representing a linear combination of the loads it would see if every possible combination of outages occurred in the plants already running when it is started. BB models make these calculations using the "load duration curve" obtained when the hourly synoptic load data for a given period (such as a season) is sorted in size order. BB models dispatch the generating units under this curve, modifying it each time a unit is added to reflect the probability that unit might not be available. The result, if the calculation is carried out accurately, is a robust determination of such quantities as plant-by-plant energy production, fuel consumption and (for some models) emission of various pollutants as well as system-wide characteristics including system net present value, LOLP, unserved energy and reserve margin.

Because the BB models work from the load duration curve, they cannot include non-dispatchable technologies such as wind or solar electric power in the probabilistic analysis; rather, such sources of power must be subtracted from the synoptic load curve before it is sorted. This is not a drawback if the problem is handled correctly, and a BB model has been used extensively to determine the potential role of photovoltaics in U.S. electric systems (Bright, 1984).

The most widely known BB model is the Vienna (Wien) Automated Systems Planning model, or "WASP" (Jenkins, 1974).

Developed at the TVA and Oak Ridge National Laboratory, WASP is maintained by the International Atomic Energy Agency in Vienna, and is widely used by them in various power development programs. To speed computation and avoid problems associated with digital truncation, WASP represents the load duration curve as an expansion in Fourier series. To optimize the overall power system over a time period of twenty or thirty years, WASP simulates many possible configurations of the system over that period, then chooses among them using a dynamic programming algorithm.

The load duration curve is a monotonically decreasing function of load, while a Fourier series is intrinsically periodic. This basic incompatibility leads to inefficiency in the representation and to the necessity for various programming devices to screen out the influence of periodic false images of the curve. These problems are obviated by the introduction of a statistically correct treatment of the loads, the "method of moments" or "cumulant expansion," which results in a description of the load duration curve by Hermite polynomials (Rau, 1980; Stremel, 1980). This results in both increased accuracy and a dramatic increase in calculational speed.

A microcomputer implementation of this method in a privately developed BB model similar to WASP, A/S Plan, uses six to ten terms in the cumulant expansion. Simulations using this model were closely compared to results from the IAEA's WASP in a recent study of Nepal's electric system (Analytical Solutions, 1995); the two calculations agreed to within 2-3%, disproving earlier claims that the cumulant method was inaccurate (Smith, 1983; Hill, 1981). The speed of the cumulant expansion calculation allowed many alternatives to be examined, as will be described below.

Externalities can be made internal through the implementation of pollution taxes, such as a carbon tax. Since BB models can carry out detailed emissions accounting, costs can be associated with emissions and optimization can be carried out including the effects of those costs. New thermal capacity in Russia must comply with emission standards. Since optimization can also be carried out within specified limits on emissions, a utility can determine optimal strategies for operating in a world which includes emissions taxes and determine the value of "offsets," or trades of emission limits between utilities. Similarly, a government agency can determine likely utility responses to such taxes and limits.

In a system as large, rich and complex as Russia's, accurate representation of the operation and interaction of myriad disparate generating units is essential for accurate assessment of the future reliability and economics of the system. It is especially important to be able to perform many runs, examining all possible systemic responses as large questionable units are removed from the loading order or are rehabilitated and returned to service. BB models are capable of performing these analyses at very reasonable costs within a centrally dispatched service area.

### **3.4 Multi-Area Reliability Planning**

However, the Russian electric system is spatially the world's largest interconnected grid, and when regional transmission and siting issues arise, they must be settled by modelling efforts external to the BB simulation and optimization process. The problem is that the computational intensity of the probabilistic simulation increases with the power of the number of areas. Thus the system that was eminently tractable when considered to exist at one point in space becomes difficult when broken into two regions connected by a tieline of specified capacity and completely unmanageable when broken into three or more regions. (Noyes, 1983)



U.S. utilities handle multi-area planning by building models whose sole purpose is to simulate transmission load flows searching, in particular, for instabilities that could lead to overloads and oscillations. Actual planning is done in the form of case-by-case studies, rather than through the use of a model examining many transmission and siting alternatives. This is appropriate in the U.S. (or western Europe) since one is invariably examining the marginal impact of one project on a huge, invariant system. At the current juncture in Russia, the plethora of options associated with rapid changes in demand and the rehabilitation or closure of many large central stations requires that multi-area models of the sort discussed in Section 4 of this report be used in conjunction with detailed probabilistic models. The interaction of these two sorts of models has not, at this point, been automated, so studies of this type will require the constant intervention of an intelligent analyst.

## 4 MULTI-DIMENSIONAL PLANNING

### 4.1 Spatial Planning Models

Incorporating a spatial dimension into the power planning problem requires adding the transshipment of a commodity, electricity, from one place to another. On the assumption that the generation mix is specified exogeneously using, for example, a probabilistic dispatch approach discussed above, the spatial planning problem can be formulated as the determination of a set of facility locations which minimizes the sum of resource extraction, electric transmission, and fuel transportation costs subject to meeting certain energy and resource mass balance constraints.

This problem can be stated in terms of a linear program (LP) with a link and node structure to allow for transport of fuel and transmission of electricity (Meier, 1980). Fuel transport occurs between a producing and a consuming node, while transmission of electricity takes place between adjacent (or pre-specified) nodes of a regional grid. Hydro generation, water resource issues and constraints on environmental emissions can be readily accommodated into this framework (Meier, 1984). The results will show, for example, where new or additional transmission capacity would be optimal to construct. A variety of objective or multi-objective functions, depending on the priorities of the analysts and decision-makers, can be used to specify and drive the model. The advantage of an LP framework is that large problems can be solved quickly and cheaply thus allowing extensive parametric sensitivity analysis, which is essential for addressing the issue of uncertainty. However, the LP formulation does introduce certain simplifications; for example, transmission losses are evaluated in terms of ohmic (DC) losses only. The resulting optimal solution would need to be checked with AC load flow studies to ensure system stability. The other disadvantage of LP in this situation has to do with the indivisibilities of transmission line (and transportation network) construction. One can start with the voltage levels of various links (and the cost functions and loss coefficients appropriate to that level), obtain the optimal power transfers indicated and then check via thermal or surge impedance loading the reasonableness of the power to be transmitted over the indicated lengths of the links at the assumed voltage level. A few iterations might be needed to ensure that the solution is reasonable. The Integrated Systems Planning Model (ISPLAN) indeed has been constructed based on this methodology and is being used by the Central Electricity Authority, India (CEA, 1996) for first-cut evaluations of thermal plant siting in relation to the planned augmentation of the national grid and coal transport network.

### 4.2 District Heating Planning

Many Russian power plants provide both electric and thermal power, the latter as a supply to district heating systems. Such plants must respond to two simultaneous load curves according to some specified dispatch strategy (meet electric load, meet thermal load, meet largest load, etc.). Usually, but not always, such units will be base load plants, simplifying the analysis. In any case, "bin" methods may be used (Guinn, 1991), where separate electric load duration curves are prepared for several different levels of thermal load. A more straightforward approach is to incorporate constraints corresponding to the thermal demands into an LP model alongside the electric demand constraints discussed in Section 4.1. Such analysis should be validated by parallel examination of the electric supply reliability using a BB model.

## 5. LINKAGES TO BROADER ENERGY MODELS

The projected demand for electric energy is generally the driver of the capacity expansion model. Consistency of the projected demand with underlying trends in the energy and the economy is desirable. It is then desirable to link the power system model with a broader energy model such as MARKAL (Goldstein, 1990), and its later variant MARKAL-MACRO, which has been extensively applied in many OECD and other countries. Energy system models generally treat the utility sector as one component of a linear programming problem, resulting in a treatment too simplified to be accepted as adequate when BB models and more sophisticated siting models are available. What is required is a plan of action for integrating the results of overall energy planning models with the results of credible utility planning models, including a feedback loop so that the utility plant that results from detailed optimization using the BB models is represented in the larger energy sector model, which in turn can then predict future electricity demand on the basis of interfuel competition. These results can then be used to generate new projected loads for the utility model, and the process iterated. The requirements that will guarantee that this process will converge are as yet unknown. For planning on the scale required in Russia it is essential that attention be paid to this problem.

## 6. THE INCLUSION OF UNCERTAINTY IN SENSITIVITY STUDIES

Russian electric utility planning is beset by uncertainties: will the economy continue to contract or rebound? How will this affect load growth (or contraction)? What future trends will characterize fuel prices and will effective payment schemes be re-established? Will effective coordination and payment schedules be established with recently independent states through which much of the unified transmission system passes? In the face of these and many similar uncertainties, planners should constantly apply two principles:

- Every study should examine the broadest possible set of options and parametric variations, to ensure that fortunate synergies and unfortunate feedback loops are uncovered, and
- Once an optimal development plan has been identified and tentatively selected, the "downside risk" associated with that plan should be extensively investigated. That is, if this plan is adopted, but the assumptions behind it turn out to be in error, what cost results? And who will bear it?

Portfolio analysis can be used to address uncertainty in energy planning. Construction of a pay-off matrix of possible outcomes

with probabilities attached is a useful tool to analyze the risk associated with an uncertain future. Downside risk assessment is particularly important as countries with previously subsidized electricity prices attempt to move to "cost-based pricing," frequently at the behest of international lending agencies. The issue is illustrated by the recent study of Nepal (Analytical Solutions, 1995) referred to earlier. Load growth largely extrapolated from a period when electricity had been priced at roughly four cents per kilowatt hour was used in a study examining the feasibility of a 400 MW hydro project. Simultaneously, electricity prices were raised over the period from 1992 to 1998 to ten cents per kilowatt hour, a 250% increase. Once a project of this magnitude is underway, it is difficult and expensive to delay it, although purchases of smaller thermal units can be adjusted. What if, instead of the assumed "base case" loads, the increased price of electricity induced substantial conservation and a "low load growth" scenario actually occurred? Clearly, optimal plans can be developed around each case, with the optimal plan for the low load case involving delays of several years in the hydro project. Careful simulation showed that if the system was planned around base case load growth, but then low load growth actually occurred, the net present value of the system costs was \$52 million above the \$545 million that would have resulted had plans been based on the (correct) low load growth assumption. Conversely, planning for low load growth and then finding that base case growth actually occurred resulted in only a \$4 million increment above the \$868 million a system correctly optimized for base case growth would have cost.

In summary, planning for base case growth and being wrong would cost \$52 million, while planning for low load growth, delaying the project and then being found wrong would cost only \$4 million. Since the cost of error is borne by the country rather than the donor agency, there is a significant difference of interests, which can only be resolved by careful study of all the alternatives. Although Russia's electric system is many times larger and more complex, it is subject to substantial pressures from various external and internal interests. Major capital projects, including both the retirement and the refurbishment of thermal and nuclear plants, should only be undertaken after a careful examination of the downside risk associated with all uncertain input assumptions, along the lines outlined here for the case of load growth uncertainties.

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