INTEGRATING REGIONAL WATER
AND POWER SYSTEMS

by

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1.   Introduction*

Electric power markets grow up around centers of urban and industrial concentration, and there comes a time in the development of these systems when it is advantageous to tie together neighboring power grids by means of extra-high voltage transmission lines.

There are several reasons why interconnection so often proves to be a profitable investment. First of all, economies of scale in project construction are quite important in the generation stage of electricity supply. Furthermore, separate reserve or standby capacity is required for each independent power market. When interconnected, the reserve requirements of the integrated network usually are less than the sum of the reserves needed for independent operation.

It also is possible to attain a more efficient overall
performance of any given set of generating facilities. By
the means of energy transfers over a multi-market connection,
full use may be made of newer and more efficient thermal
plants while less economical units are held in reserve or
are used to serve peak demands. Market integration can
allow much more effective utilization of hydroelectric
sources as well. Rainfall and stream flow patterns may differ
among interconnected regions, and better use can be made of
available water by trading energy back and forth between
markets from season to season or year to year. Surplus energy
periodically available in one system may be utilized by
another either to serve its demand directly or to pump water
into storage reservoirs.

Finally, the timing of daily power requirements may vary
between systems because the mix of industrial and residential
power demands may not be the same or because markets may be
located in different time zones. Thus the peak demand on an
integrated system may be less than the sum of the separate
peaks on its component markets, i.e., there may exist some
"load diversity" among systems. It becomes possible to meet
capacity demand in the overall grid with a smaller amount of
installed generating capacity than would be required to serve
the individual markets separately.

As systems expand and become integrated, however, the planning task becomes more and more complicated. Operating and investment decisions within any one market or region must be coordinated with the management of the electric power network as a whole. The attainment in practice of the potential savings from interconnection requires careful design and scheduling of new generating facilities in each of the regions, tight coordination of the operation policies followed by the respective sub-system managers, and the maintenance of a set of energy prices which provide adequate incentives for the movement of energy around the system.

Additional complexity is encountered when the operation of an inter-regional electric grid affects the management of other parts of the economy - as is the case when the system is fed by hydroelectric power from multi-purpose water resource developments.

Even with centralized ownership and control of electric systems the planning of such an interconnected network presents a considerable analytical problem. If the inter-connection serves a set of autonomous regional authorities, all these matters of investment selection and system operation become the subject of inter-regional bargaining, and planning calculations must serve the additional function of informing these negotiations.

This paper presents a new analytical model which can be used to support decisions on investment selection, operating policy and pricing arrangements in situations of this type. The model has been prepared for application to a proposed interconnection of four independent regional power utilities in Colombia. The revised approach is based upon digital computer simulation of the long-run capacity expansion and short-run operation of electric power systems.[1]

2. Regional Integration in Colombia

2.1 The Proposed Interconnection

The three major cities of Colombia - Bogotá, Medellín and Cali - are located about 200 to 300 kilometers apart as shown in Figure 1. Yet due to the mountainous terrain of the country, these regional centers have developed in relative isolation from one another. The capital city of Bogotá, for example, is located at an altitude of 8,000 feet, and to travel overland to Medellín one must descend to and cross the Magdalena River at about 600 feet above sea level and then climb over a 12,000 foot mountain pass before dropping into Medellín at about 5500 feet. It should be noted that these same mountains which render transportation so difficult are a source of great wealth in water resources. Much

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[1]The Colombian planning model is the latest and most complex version of an analytical technique developed originally in the context of an Argentine problem [7] and subsequently applied to a study of water and power in West Pakistan [5] [7] [8].

ATLANTIC OCEAN

Barranquilla

PANAMA

VENEZUELA

MEDELLIN
SYSTEM

Bucaramanga

Medellin

CHEC
SYSTEM

Manizales

Tunja

BOGOTA SYSTEM

Bogotá

PACIFIC OCEAN

CVC SYSTEM

Cali

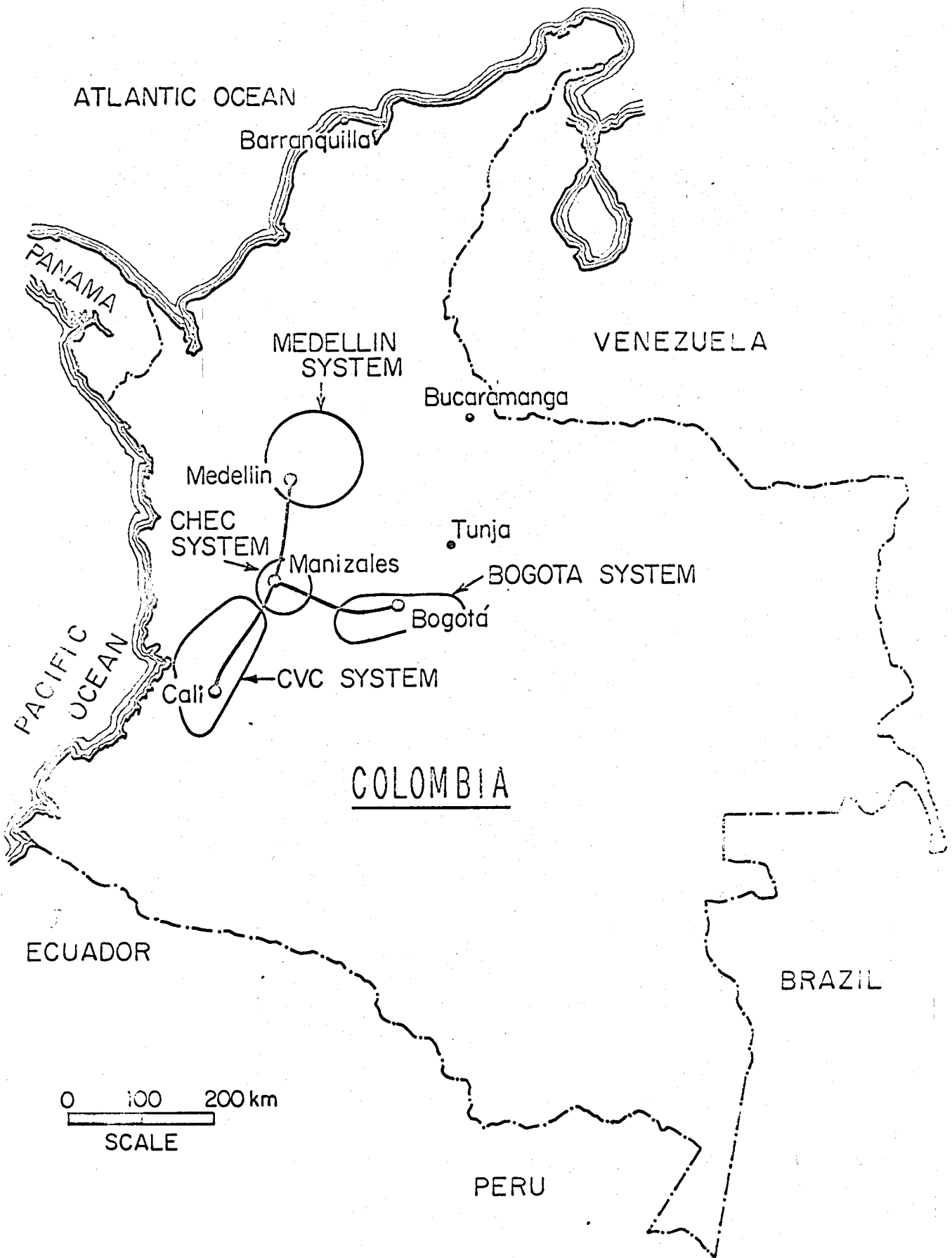COLOMBIA

ECUADOR

BRAZIL

0   100   200 km

SCALE

PERU

FIGURE 1

PROPOSED INTERCONNECTION

of the high mountain area receives tropical rainfall; Colombia is one of the world's richest countries in potential hydroelectric power development.

Because of their relative isolation, each of the major regional centers has developed its own economic base, regional institutions and personality. The management of water and power resources in each area is under the effective control of a set of distinct regional and municipal authorities. In the capital city of Bogotá, electric power is provided by a municipally owned electric utility (Energía Eléctrica de Bogotá), while municipal water supply and waste disposal as well as irrigation in the Bogotá region are the responsibility of other municipal and regional institutions.

In Medellín all electric power, water supply and waste disposal and even the local telephone utility are run by a single municipal authority (Empresas Públicas de Medellín). The city of Cali is located in the Cauca Valley, and the overall development of the resources of the region is the responsibility of a river valley authority (Corporación Autónomo Regional del Cauca) patterned after the TVA and commonly referred to as the CVC. There also is a small company in the area which provides hydroelectric generating facilities serving the city of Cali while the electric

energy distribution within the City itself is handled by a municipal public utility. For purposes of this discussion the various companies which serve Cali and the Cauca Valley will be denoted as the "CVC system".

Over the past ten years considerable study has been devoted to a possible interconnection of these markets [2] [3] [6]. Under the current plan a fourth city, Manizales, would be included in the inter-regional grid. Manizales is served by a local electric utility called CHEC (Central Hidroeléctrica de Caldas, S.A.) which is a subsidiary of a federal water and power agency which controls the electricity supply in many small power markets throughout the Country.

As shown in schematic form on Figure 1, the electrical interconnection would be in the form of a "T" with one of the major cities at each of the extremities and Manizales near the central connection point. The three major markets are of roughly equivalent size; Bogotá and Medellín both had peak demands of around 300 MW (megawatts) in 1967 while the peak in the CVC system was about 240 MW. The demand in Manizales at this time is about 75 MW. The Medellín and Manizales grids are served entirely by hydro-electric generation facilities; both the Bogota and CVC systems contain some thermal generation although they also rely primarily on hydroelectric sources of supply.

In preparation for the financing, construction and
operation of the proposed transmission lines, the interested
parties have formed an interconnection corporation (Inter-
conexión Eléctrica, S.A.) which will own and operate all
joint facilities. All the stock in the new corporation
will be held by the four utilities described above, and the
managers of these utilities form the board of directors of
the new servant institution. The board, in turn, will appoint
a manager for the interconnection company itself.

After constructing the inter-market transmission lines,
the new entity will serve as a wholesaler and shipper for
energy sales among the four markets. It also will build
and operate all new generation facilities after completion
of those now under construction or in advanced stages of
planning by the individual utilities. The agreement
which establishes the new corporation also covers various
aspects of system operation, financing and price policy,
but the details of these arrangements are beyond the scope
of this paper.

2.2 Problems Presented by Regional Integration

There are significant barriers - both economic and
political - to the establishment of an efficient inter-
market transmission network when independent regional or

municipal authorities control the different market systems.
It has required several years work and negotiation to set up
the interconnection company itself. But this is just the
first step. A host of investment and operating decisions
remain to be made within the framework of the new agreement,
and these choices require a careful balancing of the
various regional interests over against the broader national
concern for the efficient operation of the electric power
sector as a whole.

First, decisions must be made on the location, tech-
nology and scale of new generation projects. Often there
is strong regional conflict over the choice of new facilities,
particularly when water resource developments are at stake.
If large projects are to be built in order to take advantage
of economies of scale, then each new project choice involves
one region getting the new facilities and the others not.
The larger the project the longer the some regions must
wait before they can host a major physical development.
Thus when there is regional rivalry it may be difficult
to reach agreement on a sequence of investments which sat-
isfies the requirement for regional equity while providing
economies for the whole.

This difficulty is magnified when electric power is
generated by multi-purpose water resource developments. In

effect, the interconnection renders most of the water resource
planning in each region interdependent with actions taken
in all the other regions. For example, approximately 85%
of the electricity supply for Bogotá comes from the Bogotá
River. But the River also is the sole source of water
supply for this city of over two million people, and it
serves as the primary municipal waste discharge facility.
With interconnection, the management of the Bogotá River
will be intimately related to the operation of the larger
system and thereby to actions taken in Medellín, Cali and
Manizales.

Likewise, most of the proposed new hydro developments
in the Cauca Valley involve irrigation and flood control
as well as electric power generation. Still other proposed
projects are tied to major navigation schemes. Thus the
new interconnection authority faces a real challenge.
It is not simply a matter of regional competition for
electric generating facilities; very real regional economic
interests are involved in gaining the complementary out-
puts of physical facilities which will be justified and
financed primarily on the basis of electric power pro-
duction.

A further difficulty arises in the conflict over
pricing agreements and short-run operating policies. If

the different regional electric utilities are under inde-
pendent management, then large sales of energy between
markets can involve significant transfers of money. Thus
the structure of energy prices, which has a great influence
on the operating efficiency of the system as a whole,
also must be viewed from the standpoint of its impact
on the internal financial positions of the participating
parties.

Little need be said about the importance of making
the best possible decisions about investments, operating
policies and pricing arrangements in this type of situation -
particularly in a less-developed country. These social
overhead facilities take a large slice out of available
capital investment, and there is a considerable potential
benefit to the country as a whole from an effective planning
effort and a delicate balancing of these diverse regional
interests. It is no longer sufficient, however, to conduct
separate analyses of the water resources of the different
regions. Partial analyses of individual projects considered
apart from the overall system may lead to costly choices,
and the desire to inform the process of inter-regional
bargaining and decision making leads to the formulation of
a model which encompasses the four-region interconnection
as a whole.

This approach to planning is a departure from the way in which problems of this type normally have been handled in less-developed countries. The scope of analysis has not been so broad in the past, and for good reason. The detailed analysis of a complex, interdependent water and power network, if it had to be done with desk calculators and slide rules, would have required an intolerable expenditure of time as well as scarce engineering talent. Engineering consultants and planning bodies have had to be satisfied with a judicious combination of partial analyses with only loose links between the various sub-parts of the broader study.

By the same token, it has not been feasible to investigate the implications of uncertainty about certain basic economic parameters or about errors in demand forecasts. To repeat the calculations on the basis of a range of values for exchange rates and fuel prices and alternative assumptions about demand growth would have been out of the question.

With digital computers becoming ever more widely available, this need no longer be the case. If a model can be formulated which captures the essential characteristics of the system as they impinge on major planning decisions, then repetition of the calculations under a variety of assumptions is no problem; it is precisely the kind of situation where electronic computation facilities prove

their worth. Given the large expenditures which a country

like Colombia will be making in electric power facilities

and the potential savings which might be realized by more

efficient investment and management policies, the responsible

authorities can hardly afford not to make use of improved

analytical methods.

Once having argued that here is a great potential

for application of computer models in studying this type

of problem, a word of caution is in order. Computer analysis

can require considerable amounts of time and talent, and

it is important to be clear about the purpose of this

kind of activity. Presumably the objective is to serve

the decision process in each instance, and this requires

a model which can be formulated and solved within a

reasonable amount of time. Furthermore, the model should

yield results which can be understood and used by those

who actually make investment and operation decisions.

What follows is a description of an attempt to construct

a model along these lines for use by the new Colombian

interconnection corporation and by national planning officials.

The primary focus is on long-run planning of investments,

although as noted above, investment planning requires
consideration of short-run operating policies, pricing
and financial arrangements. First, the overall approach
to the problem and the structure of the planning model
are discussed. There follows a brief description of
the computer program itself, the data required, and the
information presented for each power system analysis.

3.   Formulation of an Inter-regional Planning Model

   3.1   Analysis by System Simulation

        The planning method presented here involves the
use of digital computer simulation as a tool for analyzing
potential investment in generation facilities in each of
several electric power markets, for evaluating transmission
connections among markets, and for studying alternative
schemes for operating such an interdependent system. Because
it is no longer possible to conduct an adequate analysis of
each market or new project separately, an attempt is made
to construct a model which captures the essential operating

characteristics of the interconnected system as a whole.

The analysis begins with a projection of electric power demand in each of the markets to be considered. In addition to demand forecasts, information is required on the capacity, efficiency, fuel price, maintenance and operation expenditure, and capital cost of each existing and potential thermal and nuclear generating facility. Similarly, the capital and maintenance and operation costs of existing and potential hydroelectric developments are needed along with monthly patterns of capacity and energy output. For every proposed inter-market connection scheme, data are required on the carrying capacities of each of the transmission links in each year along with appropriate cost information. Finally, the model requires ranges of values for certain economic parameters such as fuel prices, discount rates, foreign exchange rates and opportunity costs of capital.

Alternative electric power investment programs are defined which are "equivalent" in that each will meet projected demand growth in all markets with an acceptable standard of service quality. For any investment plan there may be several alternative operating schemes which might be followed. The computer program is used to calculate indicators of the relative economic attractiveness of each combination

of investment plan and operating policy and to prepare data
on the financial impact of the particular scheme on each
of the regional authorities.

The evaluation of each alternative is accomplished by
means of a two-part procedure. First, a detailed simulation
of system expansion and operation is conducted over some
planning period, say ten to twenty years. Because of the
strong interdependence between the various units which
are found on the system at any point in time, an approx-
imation of the results of hourly and daily scheduling of
generating units must be calculated in order to estimate
the fuel costs incurred in each month of the planning
period. The computer program then combines these fuel
cost data with the capital and maintenance and operation
expenditures implied by a particular investment schedule
to produce a figure for the present value of total system
supply cost over the period of analysis. This simulation
of the results of daily system operation is also the source
of information on the magnitude and timing of the transfers
of power among the different regions.

The second part of the procedure involves an adjust-
ment for the impact of different investment programs on
system cost in the years beyond the planning horizon through
the use of a simple terminal correction. The "plan period"

is that portion of the future which is simulated in detail, and at the end of this period there will be a collection of assets which is passed on beyond the horizon. The form of the final asset structure will differ according to the particular investment pattern being analyzed, and this difference will be reflected in variation in the cost to serve system electric demand in the years of the more distant future. The impact of differing terminal conditions is approximated by a set of simple functions, and the computer results are adjusted to account for these effects.

Once the model has been formulated and programmed and the initial data gathered, it is possible to analyze a large number of alternative investment schemes and operating policies with relative ease and in a short amount of time. Each simulation analysis can provide a full range of information for sensitivity testing of critical assumptions, and the model can be updated to take account of changing conditions so that it can become a permanent part of the year to year planning effort.

3.2 Equivalent Alternative Investment Plans

In order to describe how equivalent alternative plans are defined let the subscript i serve as an annual time

index, $i = 1,\ldots,N$, where N is the length of the planning
period. And let the subscript t be used as a monthly time
index, $t=1,\ldots,$ 12. The analysis is conducted on a monthly
basis because of seasonal variation in demand and in the
capability and energy outputs of most hydroelectric projects.

The main element in the demand forecast is a projection
of peak loads, P_{it}, for each month of the planning period.
System load is exogeneous to the model, and the load fore-
cast is introduced in the form of a set of constraints.
All valid investment plans must provide sufficient generation
and transmission capacity to serve projected demand, P_{it},
with a certain minimum amount of technical reserve. Plans
meeting these requirements are "equivalent" in that each will
meet the minimum prescribed standard of service quality.
It is, of course, possible to repeat the analysis under
alternative demand projections in order to investigate the
impact of forecast errors or to study the effects of policy
measures which might be used to restrict or promote demand
growth.

To facilitate the exposition, let the formulation
of this set of constraints be introduced in the context
of a single isolated market rather than in terms of the
more complex four-market grid. Suppose there are a number
of generating units, U_j, $j=1,\ldots,J$, which might be in service

during some particular year where $j=1,...,\underline{j}$ are existing
and potential thermal and nuclear units and $j=\underline{j}+1,...,J$
are the hydro possibilities. Each thermal or nuclear unit
is characterized by its rated output capacity net of in-
station losses and consumption, Q_j, for purposes of defining
alternative system expansion plans; plant output capability
is assumed constant over the year.

The output characteristics of each hydro plant are
represented by its capacity, Q_{jit}, and the associated energy,
H_{jit}, in each month of the planning period. Since the
monthly pattern of energy and capacity available from a
hydroelectric project depends on the size of the dam and
on the reservoir operation policy followed, a separate
project must be defined for each combination of physical
design and water release schedule which it is desired to
evaluate.

It is at this point that multi-purpose aspects of
water resource projects enter the analysis. Each set of
values for capacity and energy outputs over time, Q_{jit}
and H_{jit}, for a particular physical development, j, is
the result of a separate simulation of the water project
itself and will reflect the impact of conflicting uses
for project water. In order to explore the trade-off between
the contribution of a particular facility to the electric

power grid and to other water uses, a number of mutually
exclusive alternative projects may be formulated, each
differing from the others in the reservoir release policy
being followed.[2]

For each generating unit U_j there is a scale variable,
x_{ji}, which is appropriate for each year. The variable
x_{ji} is limited to the values zero and one. If plant U_j is
in the system in a particular year, $x_{ji} = 1$; if not, $x_{ji} = 0$.
During any year, the system supply structure will be composed
of some subset of U_j. Additions to and deletions from
system generating capacity are planned under a set of $12 \cdot N$
constraints of the following form.

$$0 \leq \delta_{it} = \sum_{j=1}^{\underline{j}} \frac{Q_j\, x_{ji}}{1+r_1} + \sum_{j=\underline{j}+1}^{J} \frac{Q_{jit} x_{ji}}{1+r_2} - P_{it} \quad (1)$$

The percentages of technical reserve capacity required
for thermal and hydro units are shown as r_1 and r_2 respectively.
The term δ_{it} indicates the excess reserve on the system in
month t of year i, and it must not be negative for any month
else the investment program be ruled invalid. Such a pro-
gram for the development of generating facilities is termed a
"generation plan" in the terminology of this simulation

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[2] For an example of the application of this particular approach,
see [5] [7] [8].

approach, and each plan may be denoted by a matrix of
zeros and ones, $X = \|x_{ji}\|$; $j=1,\ldots,J$; $i=1,\ldots,N$.
The particular combination of plants in existence in any
year is indicated by the appropriate column vector,

$\underline{x}_i = [x_{1i},\ldots,x_{Ji}]$.

For an analysis involving several markets, there is
a constraint of the form of Equation 1 for each month
during which a market remains an independent sub-system.
When two or more markets are interconnected, there is a
revised version of the constraint which must be satisfied
for the interconnected pool as a whole, taking into
consideration the capacities of the inter-market trans-
mission lines. Because of the complexity of the algebra,
the precise formulations of these constraints for a two,
three or four market system are omitted here.

So far as the computer analysis is concerned, each
plan is introduced in the form of two vectors which indicate
the dates when each of the planned system additions or
retirements is to be made. $\bar{S}_j$ is a "start" vector; it applies
to that subset of U_j composed of potential projects, those
for which $x_{j0} = 0$. A potential project may be introduced
at any time during the planning period, that is to say
$1 \leq S_j \leq N$. $\bar{R}_j$ is a "retire" or "stop" vector, and it
applies to that subset of U_j which is in existence at the

beginning of the planning period, i.e., $x_{j0} = 1$. Since an
existing project may be retired at any time during the plan
period, $1 \leq R_j \leq N$.

In dealing with a multi-market system in practice,
some trial-and error may be required to produce a suitable
set of equivalent alternative system plans as defined by
the capacity constraints. This is because it may not be
possible to foresee exactly how a set of several generating
facilities located in different regions will perform when
managed as a system under some particular operating policy.
Thus of any given number of plans, X, which are chosen
for analysis initially, some very likely will have to be
thrown out or modified on the basis of information provided
by the simulation analysis itself.

3.3 Total System Cost

Each power development plan which meets the con-
straints identified in Equation 1 has an associated time
pattern of capital costs, maintenance and operation expenditures
and fuel costs for each market considered. In the Colombian
case there are four markets, $k = 1, \ldots, 4$, to be served by
one of several inter-market transmission systems, T. A
major purpose of the planning model is to calculate the
value of the objective function, $G(X,T)$, the present worth

of total system cost. This function is evaluated for
various combinations of generation plan, X, transmission
scheme, T, and operating policy where

$$G(X, T) = \sum_i \left\{ [1+\pi]^{-i} [K_i(X, T) + M(\underline{x}_i, T) \right.$$
$$\left. + \sum_t \sum_k F_k(\underline{x}_i, T)] \right\} \qquad (2)$$
$$- (1+\pi)^{-N} \Gamma(\underline{x}_N, T),$$

$$i=1,\ldots,N;$$
$$t=1,\ldots,12;$$
$$k=1,\ldots,4.$$

The terms in the first set of brackets are the appropriate
discount factor multiplied by the sum of the capital, maintenance
and operation and fuel costs associated with the particular
generation plan and transmission scheme. The last term in the
equation is the terminal correction. The function of the com-
puter model is to simulate the long-run operation of the power
program described by a particular choice of (X,T) and to cal-
culate in detail the costs incurred in each month and year of
the interval $i = 1,\ldots,N$.

The cost function as represented by Equation 2 involves con-
sideration of market demand patterns, plant characteristics,
investment decisions and short-run system operation rules. The
term $K_i(X,T)$ represents the construction cost of new facilities.
The capital expenditure on any particular plant may be spread
over several years, and the cost incurred in a particular year
depends on the date of the start of construction. The capital

cost may be broken down into domestic and foreign components if desired.

The second term in Equation 2, $M(\underline{x}_i,T)$, represents plant maintenance and operation. For any year, these costs are simply summed over all facilities in existence.

The last element of system supply cost within each year of the planning period is the sum of the expenditures on fuel during each month in each market, $F_k(\underline{x}_i,T)$. The evaluation of this term for any month requires the simulation of system short-run operation, and this is the most valuable aspect of the computer model as well as the source of most of its analytical complexity. As noted above, there is strong interdependence between the system generating units in existence at any point in time. The fuel cost incurred over any interval is the result of the particular operating rules used to determine how much of the capacity of each available generating unit is used to meet the total system demand and how much power is being transmitted between markets at each instant during the interval. It is necessary to approximate the results of the instantaneous, hourly and daily scheduling or "dispatching" of the component units of the system supply structure.[3]

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[3]Additional background information on the operation of electric power networks may be found in any one of a number of standard texts [1] [9] [10] and in the publications of the various professional societies [4]. .

In order to evaluate $F_k(\underline{x}_1, T)$ for purposes of long-
run planning, one desires a method of analysis which can
capture those system operating characteristics which are of
economic significance without requiring excessive computation
expense. The model should represent system interdependency,
but only to the level of detail necessary to make wise use
of available data and to draw out those aspects of system
short-run operating characteristics which affect the
particular decisions under study.

In this model, the system energy calculation is based
on a monthly numerical approximation of the results of
optimal load dispatching. Each month the scheduling of
the generating units within each of the four markets and
the operation of the inter-market transmission system are
simulated in order to determine the power contribution of
each individual plant and the loading of each transmission
line. The energy transfers between markets will differ
according to the particular operating policy assumed to be
in effect.

On the one hand, if it is assumed that none of the
individual utilities will buy power from the interconnected
system in excess of the quantities absolutely necessary to
cover deficits in the local supply, then one operating
pattern will result. Such might be the case, for example,

if the price of energy sold over the interconnection were
set too high. If, on the other hand, it were assumed that
the price of excess hydro energy within any particular
market was always set low enough to make it attractive
to other markets to purchase the energy in order to dis-
place generation by local thermal plants, then the system
operation would be quite different. The overall supply
cost would differ and the financial transfers among the four
utilities would vary.

Full description of this procedure, which makes exten-
sive use of market integrated load functions, is beyond
the scope of this paper; it is presented in [5] and the
complete derivation of the method is available in [7]. It
should be said, however, that this numerical technique
yields a close approximation to actual system operation.
It also is possible to check these estimates of system fuel
expenditure against actual market operating records and to
adjust the calculation so as to improve the accuracy of the
analysis.

At the end of N years analyzed by the model of Equation
1 and the first part of Equation 2, there is a structure
of assets which is passed on beyond the horizon into what
might be called the "N+ period". The composition of the
system at the horizon is indicated by the final column

vector of the generation plan matrix,

$\underline{x}_N = [x_{1N},...,x_{jN},..., x_{JN}]$. and by the particular transmission scheme in place, T. An attempt is made to isolate those differences in the characteristics of the $(\underline{x}_N, T)$ associated with different plans which are likely to have a significant influence on system cost in the N+ period.

For example, a power program composed primarily of conventional thermal units will impose higher fuel costs on the system in future years than one including heavy investment in hydroelectric facilities. The full impact of these differences among power programs during the planning period is reflected in the simulation analysis itself; the influence of different programs on succeeding years is captured by means of a set of simple continuous functions which are combined into a single cost adjustment, referred to here as a terminal correction, $\Gamma(\underline{x}_N, T)$. If an appropriate correction is not made, this fixed horizon model will bias selection against long lived and capital intensive alternatives and in favor of retaining old generating equipment on' the system.

The simulation over a plan period is necessary in order to caputre the interdependence which characterizes electric power systems. It was stated above that one should build complexity into the model of daily system operation only

insofar as necessary to capture the impact of these short-
run system characteristics on the decisions under study.
By the same token, one should simulate only as many years
of system expansion and operation as are necessary to
capture the interdependence among decisions at different
points in time as they affect today's choices. Simulation
computations can be expensive, and one should carry this
detailed calculation only to the point where it is possible
to capture in a set of simpler functions the essential
aspects of the future as they impinge on current decisions.
For further details of this procedure, see [7].

4. Computer Simulation of the Colombian System

A digital computer simulation program has been pre-
pared for the Bogotá-Medellín-CVC-Manizales interconnected
grid. The program was prepared originally on an IBM-7094
computer; it is now being revised so it may be solved on the
largest and most flexible machine currently available in
Colombia, an IBM-1620. In the 1620 version it can handle
a planning period of twelve years. In any one computation
run up to twenty existing and potential hydroelectric plants
may be considered along with a maximum of ten thermal plants
and two alternative transmission plans.

Given the input data described briefly above, the computer model is designed to provide the information necessary to allow comparison of alternative patterns of system capacity expansion and operation over the planning period. For each plan analyzed, several types of detailed information prove useful. Of particular interest are data on the load dispatching for each month in each of the markets and on the operation of the transmission system for they help the analyst to get a feel for the internal workings of the system under the operating rules assumed. There also is an annual system cost summary which may be printed out for each year of the planning period.

The final result of each simulation run is an economic summary of the plan as a whole; it is presented as an array of numbers representing the discounted present worth of the total cost of the program over the planning period under the various assumptions about economic parameters. With the application of a terminal correction these figures become values of $G(X, T)$ as presented in Equation 2.

Test computations have been made with the Colombia model; its full application is yet to come. It is expected that the model will be used by the new interconnection company and by the national planning directorate to study the national and regional impacts of future investment

plans, operating policies and pricing agreements. It also
may be used, if desired, to verify the economic attractive-
ness of the interconnection itself. And it is possible
that additional sub-routines may be added to the model
by the interconnection company or by the individual utilities
so it may be used to calculate more complete data for
financial planning.

Once the model has proved its usefulness in the Colombian
context - and previous experience with this approach in
other situations indicates that it will - it is hoped that
it will be continually improved and used and thereby
aid the water and power sectors to make their most effective
contribution to the economic developments of Colombia.

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