DEREGULATION, PRIVATIZATION, AND COMPETITION: TRANSMISSION PLANNING UNDER UNCERTAINTY

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Abstract: Competitive markets expose transmission planners to new uncertainties. These are handled using a decision-analysis approach whose key contribution is quantifying and minimizing risk. The method is applied using existing and generally-available software tools. The result is a transmission plan which is robust in the face of uncertainties. A study of a major proposed Central-American interconnection illustrates the problem and the method.

Keywords: Power transmission planning, decision-making, uncertainty, risk, robustness, competition.

I. INTRODUCTION

A. *Why Should You Read this Paper?*

A method is developed for dealing with new transmission planning uncertainties in a changed and still changing electric power sector.

In the old days, a vertically-integrated utility supplied all the electric service within its franchise area. Plans for long-lead-time power plants were developed with some communication with the transmission planning department, but with the tradition that whatever transmission was needed could in fact be provided. Shorter-lead-time transmission facilities were planned after generation plans were in place and in response to gradual growth of load. Recovery of investment in transmission facilities was guaranteed by the regulatory compact [1].

PE-198-PWRS-0-05-1998 A paper recommended and approved by the IEEE Power System Analysis, Computing and Economics Committee of the IEEE Power Engineering Society for publication in the IEEE Transactions on Power Systems. Manuscript submitted December 12, 1997; made available for printing May 18, 1998.

Today in the US and in much of the rest of the world, new generation increasingly is being built by independent power producers or by an organizationally-isolated generation business unit. By business strategy or by law, information flows from generation planners to transmission planners may be restricted. As a result, and because of lengthened lead times for transmission construction, location and operation of future power plants may not be known at the time transmission commitments must be made. Transmission planning may be the responsibility of an external organization. It may be unclear who has the responsibility or opportunity to build a new line. Capital recovery may be uncertain; in the extreme, individual lines may be business units or companies with revenues tied to their contribution to system operations [2 - 5].

B. *What is New?*

Decision-analysis tools have previously been used in electric utility resource planning, particularly in least-cost planning [6, 7]. This paper shows how decision-analysis and transmission-planning tools can be combined in a powerful new way. Planners can quantify and manage risk. Plans can be identified which are more robust in the presence of the uncertainties mentioned above. Hedges can reduce risk.

C. *How Has It Been Tested?*

The method described was applied to a complex strategic transmission planning study for six Central-American countries. Existing and planned interconnections did not have the required capacity. A new trunk interconnection of some 1800 km was proposed, to improve the efficiency and reliability of the local power sector by facilitating a regional electricity market.

A key uncertainty was the degree of coordinated planning and operation of this future market. Some large regional plants (mainly hydro) are under consideration but may not all materialize. Load growth and location of future thermal plants are uncertain, as is the future development of the local transmission system in each country. These uncertainties all translated into uncertainties in utilization of the interconnection. Finally, the construction cost will be huge -- and uncertain.

II. UNCERTAINTIES, OPTIONS, AND ATTRIBUTES

Several key constructs are defined in the sidebar. See also Fig. 1. Three common ways to model uncertainty are:

- Probabilistic random variables,
- Unknown-but-bounded models, and
- Fuzzy sets.

Probabilistic representations contain the most information of the three, but are inappropriate if good probability models are not available and in situations where the law of large numbers does not apply. In these cases, unknown-but-bounded models, though seemingly cruder, are more correct. Fuzzy sets can reflect uncertainties in the parameters of either of the other two. The approach developed in this paper can use any of these three models.

Attributes represent stakeholders objectives. They may be difficult to measure. Some attributes may be quantified in monetary terms; for others, attempting to do so is unnatural and leads to bizarre results. The attributes may conflict, though discussing this particular issue is beyond the scope of this paper [7].

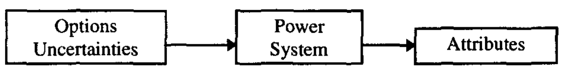

Fig. 1 Options, Uncertainties, and Attributes

Definitions

Attributes are measures of goodness of a plan: cost of electricity, earnings per share, loss of load expectation, etc. Attributes are functions of options and uncertainties.

A future is a set of outcomes or realizations of all of the uncertainties, for example: "3%/year load growth and 1%/year real oil price increase."

One chooses from a set of options: a 230-kV double circuit line, a single-circuit 500-kV line, etc.

A plan is a set of specified options: build a 230-kV line, but not a 500-kV line, along a specific route, in year 2000.

Risk is the hazard to which one is exposed because of uncertainties.

Regret is a measure of risk. For a particular future, regret is the difference between the value of an attribute for a particular plan, and the value of that attribute for the optimal plan for that future.

A robust plan has zero regret for all futures.

Uncertainties are beyond the planner's foreknowledge or control: load growth, fuel prices, regulatory changes, etc.

III. ANALYTIC PROCEDURE

A. Problem Formulation

Proper formulation in terms of options, uncertainties, and attributes is the most important and most difficult step in solving a planning problem. Options must be selected carefully (and as in the example below, may change in the course of a study). Ranges and combinations of uncertainties must be identified. Attributes must be chosen which reflect significant objectives and which can be measured with the tools at hand.

B. Transfer Capability

We do not have a perfect measure of the strength or capability of a transmission network – this is an important unsolved problem. About the best measure now available is transfer capability. Transfer capability can be used as a computational convenience to tie transmission options to attributes.

The transfer capability of a network cannot be measured directly. It is computed using simulation tools. The North American Electric Reliability Council defines transfer capability as the maximum transfer such that:

1. With all elements in service all flows and voltages are within normal ranges;
2. The system remains stable after any single contingency; and,
3. After any single contingency all flows and voltages are within emergency ratings.

Transfer capability is a function of reliability criteria, transmission and generating element maintenance, loads, dispatch, etc., and is therefore a random variable whose value can change from minute to minute [8].

C. Simulation to Measure Attributes

Available or specially-constructed simulation tools are used to compute attribute values for various combinations of options and uncertainties. The tools used depend on the attributes chosen, and might include production simulation programs (to compute fuel cost, reliability, fuel use, and emissions), corporate models (to calculate return on equity, cash flows, etc.), dispersion models (to estimate ground-level concentrations of pollutants), etc. Network analysis packages are used to compute transfer capability.

D. Decision Analysis: Risk and Robustness

Exposure is one measure of risk [7]. Two dimensions of exposure are:

1. How great is our regret if we choose a particular plan, and if a future that is adverse for that plan occurs?
2. What futures are adverse for a particular plan, and how likely are they?

Suppose that the value of a particular attribute for a particular plan and future is:

$$a_{i,j} = f(p_i, f_j), \text{ and} \quad (1)$$

$$a_{optimal,j} = f(p_{optimal}, f_j), \quad (2)$$

where $p_{optimal}$ is an optimal plan for future f_j. Then the regret is

$$r_{i,j} = a_{i,j} - a_{optimal,j}. \quad (3)$$

Regret is zero for an optimal plan for a particular future. If the regret is zero for that plan for all futures, that is, if the same plan is optimal for all futures, then the plan is robust.

If there is no robust plan, and a choice has to be made among the various possible plans, then there are a number of possible strategies. One might choose the plan which minimizes the maximum regret, or which minimizes the average regret, or which maximizes the maximum benefit, etc., depending on one's tolerance for risk [7, 9]. These ideas can be extended in a natural way for multiple-objective problems.

It is sometimes possible to design a hedge or an insurance policy to eliminate regret for a particular plan, thereby creating a robust plan. Whereas computing regret and choosing a plan based on a particular strategy is an exercise in mathematics, developing a hedge requires creating and analyzing new options.

IV. EXAMPLE: CENTRAL AMERICAN INTERCONNECTION

A decade ago ENDESA, a Spanish utility acting in behalf of the government of Spain, began promoting a single-circuit 500-kV line interconnecting six Central American countries. The line would parallel a partly-existing and partly-planned single-circuit 230-kV interconnection. The highest-voltage existing or planned internal network in each country is 230-kV. The peak load forecasts for 2000 in the six countries are between 450 MW (Nicaragua) and 1000 MW (Costa Rica).

The Inter-American Development Bank was approached for funding. Staff members were concerned whether this was the right option. Power Technologies, Inc. (PTI) and Instituto de Investigación Tecnológica (IIT) were engaged to address this concern in a cooperative study involving the utilities in the six countries [10].

A. Problem Statement: Uncertainties, Options, Attributes

Alternatives to the single-circuit 500-kV line were to do nothing, 230-kV lines in various configurations, and single or double circuit lines at higher voltages (400 kV or 500 kV). These, along with some routing alternatives, were the options.

The principal uncertainties were load growth, the degree of cooperation and coordination in operation and planning in the isthmus, generation expansion plans (including four possible large regional hydro plants in three of the six countries), line construction costs, and line operating benefits. For convenience, the first three uncertainties were spanned by six futures. Three had low load growth (about 4.4%/year) and three high (about 6.8%/year). Three of the futures included up to four large regional hydro plants. The futures represented various levels of international coordination in planning and operations.

The uncertainty in generation plans was greater than normal because in a privatized and competitive power sector the transmission owner does not control the siting, timing, and dispatch parameters of independent power producers. The degree of international coordination is uncertain since it depends on how the regional and national power sectors evolve and are restructured.

The attributes were construction costs, operating cost savings, and the difference between the two, annualized and present-worthed (net benefit).

B. Transfer Capability Calculation

Table 1 shows the approximate construction cost and transfer capability associated with various line options. Thousands of steady-state and dynamic contingency analyses were performed, using PTI's PSS/E and TPLAN packages, to determine transfer capability. Construction costs were estimated from similar projects.

The transfer capability is about 50 MW for the existing and already-planned single-circuit 230-kV interconnection, even though the thermal rating of the line is about 300 MW. This is because the most severe contingency (opening the intertie) would create islands, one of which would be generation deficient. The individual countries cannot lose more than about 50 MW of generation or imports without loss of load.

TABLE 1
INITIAL OPTIONS: COST AND TRANSFER CAPABILITY

New Circuits	kV	Constr. Cost ($M)	Transfer Capability (MW)
0	230	0	50
1	230	190	300
2	230	295	600
0	230	0	50
1	400	N/A	300
2	400	723	1200
0	230	0	50
1	500	N/A	300
2	500	906	1500

The next circuit, be it 230-kV, 400-kV, or 500-kV, brings the transfer capability up to about 300 MW, even though the thermal rating of the higher voltage lines is over 1000 MW. But the loss of this circuit would cause all the power it was carrying to flow on the parallel 230-kV *interconnection*, whose thermal rating is, about 300 MW. Therefore the interconnection cannot be loaded beyond this value, and a single-circuit 400-kV or 500-kV line provides no more transfer capability than does a 230-kV line.

A double-circuit 400-kV or 500-kV line would have a very high transfer capability.

The above is a simplification of the analyses actually performed, which included contingency analysis to determine limitations due to thermal, voltage, and stability concerns. Attaining the transfer capability levels indicated requires some modest internal reinforcements to avoid voltage and thermal problems under some contingencies. For one of the interfaces the north-to-south limit is actually a bit below the nominal 300 MW even with these fixes. Stability problems will not limit inter-area transfers. The transmission costs embedded in Tables 3 - 5 include normal levels of compensation.

C. Production Simulation

IIT created representative generation expansion plans for each of the six futures. IIT then simulated the operation of each of them from 2000 to 2015 with various levels of transfer capability. Both the expansion planning and the simulation were done using SUPER, a hydro-thermal program developed previously under sponsorship of the Inter-American Development Bank.

Table 2 shows the 1996 present worth of expected operating cost savings (2000-2015, ignoring transmission capital costs) for the six futures as a function of transfer capability. For four of the futures there was no economic benefit for transfer capability over 300 MW. In future 6 (high load growth, four large regional hydro plants, and high international coordination in operation and planning), there was no economic benefit for transfer capability over 500 MW. In future 5 there was no economic benefit for transfer capability over 700 MW.

These observations eliminated the 400-kV and 500-kV options, since 700 MW of transfer capability could be achieved at lower cost using multiple 230-kV lines.

D. Decision Analysis

Table 3 shows the net benefit of a number of 230-kV options. Net benefit is the difference in present worth between operating cost savings and annualized capital costs of the transmission options. The net benefits of the optimal plan(s) for each future are highlighted.

The 1 x 230 option is a single-circuit line on single circuit towers. A double-circuit line on double circuit towers is 2 x 230 – the notation (1) means that only one circuit is strung, while (1,2) means one circuit is strung initially (year 2000) and a second later (2008) if conditions warrant it. The 1 x 230 (00,08) option is a single-circuit line in 2000, followed by an independent single circuit line in 2008 if it is needed. The 1 + 2 x 230 option is a single-circuit line in 2000 followed by a double-circuit line, if needed, in 2008.

TABLE 2
TRANSFER CAPABILITY AND OPERATING SAVINGS

TransCap (MW)		Operating Savings - PW ($M1996)					
2000-07	2008-15	F1	F2	F3	F4	F5	F6
50	50	0	0	0	0	0	0
300	300	96	146	256	281	809	1248
300	500	96	146	256	281	865	1288
300	700	96	146	256	281	881	1288

TABLE 3
NET BENEFITS FOR VARIOUS OPTIONS AND FUTURES

	Net Benefits (PW -$M 1996)					
New Lines	F1	F2	F3	F4	F5	F6
None	0	0	0	0	0	0
1 x 230	-27	**23**	**133**	**157**	686	1,125
2 x 230 (1)	-57	-7	103	128	656	1,095
1x230(00,08)	-27	**23**	**133**	**157**	**706**	**1,129**
2 x 230 (1,2)	-57	-7	103	128	698	1,121
1 + 2 x 230	-27	**23**	**133**	**157**	702	1,110
Max Benefits	**0**	**23**	**133**	**157**	**706**	**1,129**

TABLE 4
REGRET

	Regret (PW-$M 1996)						
New Lines	F1	F2	F3	F4	F5	F6	Max
None	0	23	133	157	706	1,129	1,129
1 x 230	**27**	0	0	0	20	4	**27**
2 x 230 (1)	**57**	30	30	30	50	34	57
1x230(00,08)	**27**	0	0	0	0	0	**27**
2 x 230 (1,2)	**57**	30	30	30	8	8	57
1 + 2 x 230	**27**	0	0	0	4	20	**27**

In Table 4 regret is computed for each plan and future by subtracting the net benefit from the maximum benefit (Table 3). The maximum regret is highlighted for each option. A new single-circuit 230-kV interconnection in 2000, followed by a second one later if necessary, minimizes the maximum regret.

The minimum maximum regret is greater than zero, though, so this flexible plan is not robust. This plan is regrettable only in future F1, which is characterized by very low international cooperation. The Bank hedged - creating a robust plan - by agreeing to make funds available for the line only after the countries of the isthmus prove that future F1 will not occur by increasing the level of cooperation using the existing network. The Bank provided modest funding to help the countries make the necessary institutional reforms: hedges are not free.

A more complete analysis, illustrated in Table 5, included uncertainties in line construction costs and production cost savings (± 20%). With the hedge described above, the plan is almost robust. The greatest exposure is in future F2, if the construction costs are 20% high and the operating savings are 20% low. This option is robust enough that it is the basis for the on-going Central American interconnection.

Table 5

Regret with Uncertainties in Costs and Operating Savings (NPW-$M1996)

Lines	F2	F2	F2	F2	F4	F4	F4	F4	F3	F3	F3	F3	F5	F5	F5	F5	F6	F6	F6	F6	Maximum
Transmission Costs	80%	80%	120%	120%	80%	80%	120%	120%	80%	80%	120%	120%	80%	80%	120%	120%	80%	80%	120%	120%	
Operating Savings	80%	120%	80%	120%	80%	120%	80%	120%	80%	120%	80%	120%	80%	120%	80%	120%	80%	120%	80%	120%	
None	18	77	0	27	106	209	57	159	126	238	77	189	565	914	501	847	903	1,419	851	1,355	1,419
1 x 230	0	0	31	0	0	0	0	0	0	0	0	0	16	42	2	24	3	19	0	5	**42**
2 x 230 (1)	24	24	67	36	24	24	36	36	24	24	36	36	40	65	37	60	27	43	36	41	67
1x230(00,08)	0	0	31	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	11	0	**31**
2 x 230 (1,2)	24	24	67	36	24	24	36	36	24	24	36	36	6	10	9	9	6	6	20	9	67
1 + 2 x 230	0	0	31	0	0	0	0	0	0	0	0	0	3	0	11	4	16	16	34	23	**34**

V. CONCLUSIONS

Today transmission planners face new uncertainties and risks, with greater penalties for being wrong. The transmission planning approach developed in this paper allows planners to quantify and hedge risk and to identify robust plans. While the method is applied using existing software, it is a radical departure from standard transmission planning practices. It yields powerful results and high-quality plans.

VI. ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions of their colleagues in PTI, IIT, ENDESA, the Inter-American Development Bank, and the electric utilities of the six countries of Central America. This work was funded in part by the US Trade Development Agency and by the Government of Spain.

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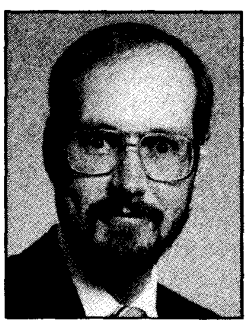
VIII. BIOGRAPHIES

Teófilo De la Torre received his Civil Engineering degree from the Universidad de Costa Rica in 1960. He did advanced studies in planning, hydroelectric development, and public administration. He joined Instituto Costarricense de Electricidad, the national electric utility of Costa Rica, in 1960 and retired in 1995, having served as manager of electrical planning and as president and CEO for fifteen years. He is currently the executive secretary of the proceeding for the electrical interconnection of the Central American countries (SIEPAC).



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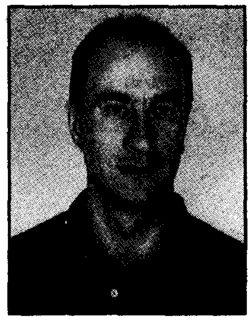

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