Transmission Planning in Developing Countries: Criteria and Risks

Daniel Cámac, *Member, IEEE* — Raúl Bastidas, *Non-member, IEEE* — Ramón Nadira, *Senior Member, IEEE* — Carlos Dortolina, *Senior Member, IEEE* — Hyde M. Merrill, *Fellow, IEEE*

***Abstract*—Transmission planners in developing countries must define and apply planning criteria, and face risks, that may differ from those of developed countries. Planners must evaluate difficult tradeoffs between costs, reliability, environmental impacts, etc. They often must plan the transmission system without knowing what future generators will be built. Appropriate planning criteria simplify the evaluation of the conflicting objectives. Risk analysis measures robustness, exposure, and regret. Non-financial hedges can reduce risk. Development of new planning criteria, and their application under uncertainty, is illustrated by a recent planning study of the Peruvian electric transmission system.**

***Index Terms*—Decision-making, electric power markets, interconnected power systems, risk analysis, robustness, uncertainty, power system economics, power transmission planning, power transmission reliability.**

I. Introduction

Methods are presented for transmission planning in developing countries. These deal with uncertainty and risk. Planning criteria resolve important conflicting objectives. Simply applying criteria used in developed countries is inappropriate.

A. The Context of this Paper

In the past, plans for long-lead-time power plants were developed assuming that transmission could be planned later as needed. In developing countries, generation is built rapidly, often to meet high load growth, by independent power producers. There may not be a long-range generation plan. Transmission planners may have short notice of transmission needs.

Transmission construction, especially financing and negotiating, may take longer in developing countries. This means that major transmission decisions have to be made earlier, in the face of great uncertainty as to generation development. For example, Central America's SIEPAC line, under construction as of this writing, has been under study and negotiation since the 1980s [1].

Uncertainties in how much transmission is needed and where, in how long it will to build, etc., pose significant risks for transmission planners.

Balancing conflicting objectives is a classic engineering problem. For instance, more reliability is desirable, but it costs more money, which is not desirable. Today conflicting objectives among power system stakeholders are increasingly pervasive and resolving them is increasingly strident [2].

Resolving these conflicts through such power system planning criteria as "n-1" and "one day in ten years" is lost in antiquity. These criteria allow the planner to avoid the difficult evaluation of "How much reliability does the system need?" and "How much is reliability worth?" for every proposed project.

Developed countries have ready access to capital, with commercial, industrial, and social structures that depend on universal access to reliable power. Access to electricity is viewed almost as a necessity, with charities trying to ensure that no one is left out.

In developing countries, access to power is sometimes viewed as a human right, but one whose attainment, along with other rights, is in the future [3]. They face limited capital, less ability to pay for electricity, and areas or populations with commercial, industrial, and social structures that do not depend on access to electric power. Planning criteria should recognize these differences.

B. What is New in this Paper?

Tools have been developed for planning with conflicting objectives and risk. With some exceptions the application has lagged the theory [1], [2], [4], [5], [6[, [7], [8], [10]. This paper makes three principal contributions.

1. It shows how formal resolution of conflicting objectives can be used to set planning criteria in developing countries.
2. It shows how transmission planning can exhaustively recognize uncertainties and risks by analyzing hundreds of possible futures. Such exhaustive analyses have been reported previously for resource planning. Transmission planning studies have heretofore been limited to a handful of futures [1].

D. Cámac (dcamac@hotmail.com) is Vice Minister of Energy and Mines in Lima, Peru.

R. Bastidas (rbastidas@osinerg.gob.pe) is with the Organismo Supervisor de la Inversión en Energía y Minería (OSINERGMIN), Lima, Peru.

R. Nadira (ramon.nadira@siemens.com) and C. Dortolina (carlos.dortolina@siemens.com) are with Siemens Energy, Inc., Houston, Texas 77079, USA.

H. M. Merrill (hm@merrillenergy.com) is with Merrill Energy LLC, Salt Lake City, Utah 84101, USA.

Panel Session, "Transmission Planning and Pricing," IEEE PES 2009 General Meeting, Calgary, 28 July 2009

3. Development and application of planning criteria, and dealing with risk, are demonstrated in a major long-range transmission system planning study for the transmission system of Peru.

II. Selecting Criteria

Fig. 1 illustrates the classic but hard-to-quantify conflict between cost and reliability.

In theory, this conflict should be evaluated for every planning decision. But doing so would be laborious and impractical. Criteria are set so that planners can avoid constantly asking, "How much reliability is worthwhile?" The trade-off relationship of Fig. 1, though usually not quantified, is the hidden, subjective determinant of such criteria as:

- LOLP < one day in ten years, used in generation planning. (Why not one day in five years, or one day in twenty years, or one day in 2π years?)
- The n-1 criterion, used in transmission planning. (Why not n-0 or n-2? What constitutes a single contingency? What exceptions should be allowed?)

Once the criteria are set, the planner no longer has to worry about Fig. 1. He just needs to satisfy the criteria.

It is important that the same criteria are not necessarily valid for all systems. The transmission system serving Manhattan, New York, should be designed to stricter criteria, providing higher reliability, than the system serving Manhattan, Kansas.

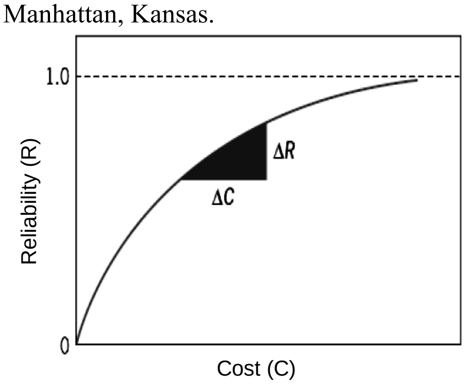

Fig. 1. Each increment of reliability costs more than the previous one [9]. At what point should one say, "That is enough reliability"?

A. Peru: Power System

Since we will use a Peruvian study to show how criteria are set and applied, we pause for a brief partial description of the Peruvian power system.

Peru's interconnected system (SEIN) has been fundamentally radial, with meshes mainly in the Lima area. As the SEIN develops, it is becoming more meshed. The backbone transmission system consists of 220-kV and some 138-kV circuits. Most transmission is bid, built, and operated on a cost-recovery basis, under regulator-approved plans.

Peru's installed capacity in 2006 was about 6,600 MW, of which about 5,500 MW (60% hydro, 40% thermal) is integrated into the SEIN. Most new generation will be gas-fired, with major generation just south of Lima at the end of a pipeline from the Amazon basin. Future availability of gas elsewhere may change this picture, though.

The growth rate is expected to be about 9%/year. The peak demand in 2006 was about 3,500 MW. This seems to imply that the generation is overbuilt, but the hydro system has little storage capacity. Hydro units may be available for limited hours, at reduced capacity. This means that the operation of the generation system depends on an uncertainty: whether it rains. This may affect the loading on the transmission system. See Fig. 2.

B. Transmission Planning Attributes

Transmission attributes used for planning must reflect transmission planning decisions, their effects, and the realities of the system.

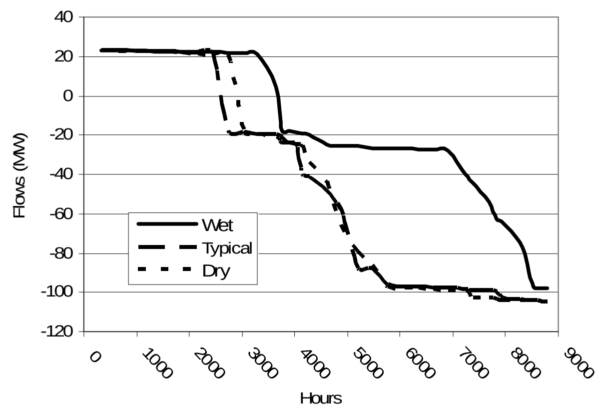

Fig. 2. Simulated distribution of flows on Peru's Talara-Piura 220-kV line may be affected significantly by hydro conditions.

For example, variations in the EUE (expected value of unserved energy) usually are dominated by variations in generation. Variations in indices like SAIFI (system average interruption frequency index) or SAIDI (system average interruption duration index) are dominated by distribution problems. It is difficult to relate changes in the transmission system to changes in interruption probabilities as seen by the consumer, in part because of hard-to-model mitigation measures that are employed before load is interrupted [10]. Therefore measures like EUE, SAIFI and SAIDI are not helpful for transmission planning.

Specifically, "transmission reliability metrics need not get down to the measurement of impacts in terms of loss of customer load. . . . air traffic congestion is rarely the cause of loss of passenger lives; therefore, it would not make sense or be necessary to measure air traffic efficiency by the expected loss of passenger lives. Rather it makes more sense to measure air traffic performance by congestion and time delay . . . Likewise, the key physical performance measure of a transmission grid is congestion or overloads" [10].

The authors identified four attributes, appropriate to Peru, that measure the effect of a transmission project on the power system.

1. Project capital cost, measured in dollars. (U.S. planners might be more comfortable with present worth of

revenue requirements, but this differs from capital cost by just a constant.)

2. NMO ("service at n-1"), measured in MW: change in the load and generation that are connected to the balance of the SEIN on an n-1 basis, that is, whose service can withstand any single contingency.
3. HDN ("Hours of Non-economic Dispatch"): change in the expected number of hours per year of redispatch due to congestion. See Fig. 3.
4. MFI ("MWh of Interrupted Flows"): change in the expected annual flows interrupted by congestion, without redispatch. See Fig. 3.

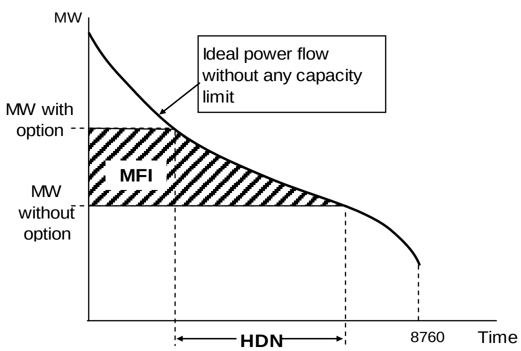

Fig. 3. Flows on a line or interface with transmission capacity constraints (in MW), with and without an option, and their effects on the MFI and HDN indices.

The change in NMO is computed by summing generation and demand that can now be served with reliability n-1. NMO measures reliability as perceived by the users of the grid – generators and consumers.

This NMO attribute is only meaningful for a system in transition from radial to meshed. For a meshed system, variations of the classic n-1 criteria can be considered [11].

The NMO attribute does guide extending the national grid to isolated areas. A similar NMZ ("n-0") criterion could be used. This political-social-economic issue requires policy guidance such as was given by US President Franklin D. Roosevelt on electrifying the US countryside in the 1930s.

HDN and MFI are computed using a stochastic dual dynamic programming simulation program with an imbedded network model. HDN and MFI measure how well the grid allows the dispatch to be optimized without being impeded by transmission constraints.

Not all transmission projects will benefit the system in the same way. Some will improve NMO; others will improve HDN or MFI or combinations of the three.

III. Setting Criteria

A. Trade-offs in General

We set criteria by picking two attributes that conflict and finding the knee of the trade-off curve relating them. The knee is the region, not necessarily a single point, of diminishing returns, where, for example, reliability gets much more costly. This loose definition is adequate, but it can be made precise [2]. As will be seen, the precise values of the criteria are not critical.

B. Peru: HDN, MFI, and NMO Criteria

The authors computed HDI and MFI for eight projects – some built recently, some only studied – for which careful cost analyses were available (Table I).

Fig. 4 shows the cumulative values of HDN versus capital cost from Table I, sorted in increasing values of HDN/Cost. The knee of this trade-off curve is evident – it is between 37 and 175 hours of HDN per year per million US dollars invested. The criterion was set at an intermediate value of 100.

TABLE I
Transmission Projects Used to Quantify Trade-offs Between HDN and Cost and MFI and Cost

Proyect	Capital Cost (Millions)	HDN (hours)	HDN/cost (hours/$M)	MFI (GWh)	MFI/cost (kWh/$)
Aguaytía-Pucallpa	$ 12	8760	**739**	n.d.	n.d.
Paramonga-Aguaytía	$ 40	8760	**217**	958	**23.8**
Cajamarca-Moyobamba and Tocache-Bellavista	$ 46	8760	**190**	n.d.	n.d.
Moquegua-Puno	$ 23	4075	**175**	54	**2.3**
Mantaro-Socabaya	$ 208	7746	**37**	621	**3.0**
Marcona-Socabaya	$ 61	1014	**17**	51	**0.8**
Vizcarra-Pachachaca	$ 35	0	**0**	0	**0.0**
Moquegua-Los Heroes	$ 14	0	**0**	0	**0.0**

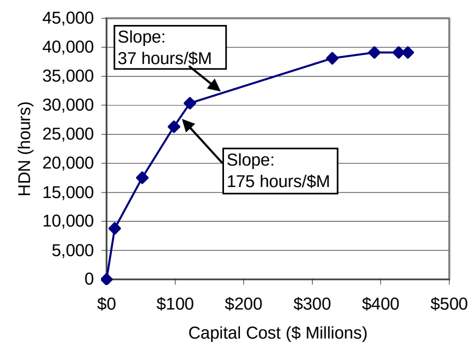

Fig. 4. Accumulated HDN and Capital Cost for Table I projects.

Fig. 5 shows the cumulative values of MFI versus capital cost from Table I. The knee of this trade-off curve is between 3 and 24 kWh of MFI per year per US dollar invested. The criterion was set at 15.

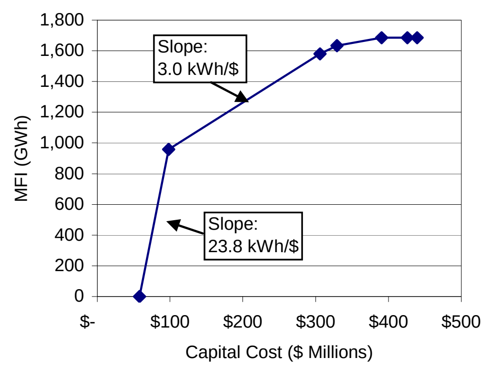

Fig. 5. Accumulated MFI and Capital Cost for Table I projects.

The values for NMO and capital cost for the same eight projects are shown in Table II and plotted in Fig. 6. The knee is less pronounced, but there are big differences in slope. The criterion was set at 3 Watts of NMO per dollar.

C. Updating Criteria

These criteria can be updated by repeating the analysis described above. More easily, they can simply be ratcheted up if the number of projects that passes is impractical for financing or other reasons, or down if the opposite occurs.

As noted, the NMO criterion will become meaningless for Peru once the system evolves past its present radial character.

TABLE II
TRANSMISSION PROJECTS USED TO QUANTIFY TRADE-OFFS BETWEEN NMO AND COST

Project	NMO Demand (MW)	NMO Generation (MW)	NMO Total (MW)	Capital Costs (Millions)	NMO/Cost (W/$)
Vizcarra-Pachachaca	0	202	202	$ 35	**5.7**
Moquegua-Puno	20	108	128	$ 23	**5.5**
Paramonga-Aguaytía	113	104	216	$ 40	**5.4**
Moquegua-Los Heroes	24	36	60	$ 14	**4.4**
Aguaytía-Pucallpa	24	25	49	$ 12	**4.1**
Marcona-Socabaya	117	55	172	$ 61	**2.8**
Cajamarca-Moyobamba and Tocache-Bellavista	52	25	77	$ 46	**1.7**
Mantaro-Socabaya	125	125	250	$ 208	**1.2**

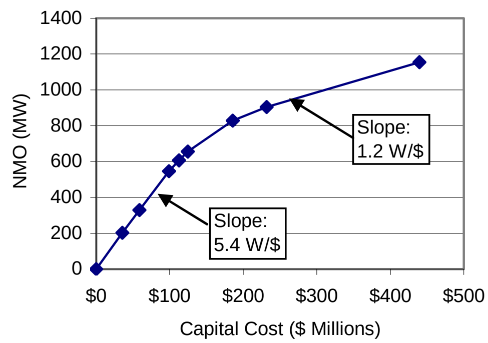

Fig. 6. Accumulated NMO and Capital Cost for Table II projects.

IV. RISK ANALYSIS

Risk is the hazard to which a system is exposed because of planning decisions and uncertainties. It is important that to have risk requires both choice and uncertainty [12]. Choosing which horse to bet on has risks. (So does choosing not to bet on horses at all.)

The financial community measures risk in monetary terms, but doing so is not necessary. In fact, attempting to do so can be counter-productive in power system planning.

Three important dimensions of risk are:

- Robustness,
- Exposure, and
- Regret.

Robustness has to do with whether a particular plan or planning decision may be regrettable, due to possible adverse realizations of uncertainties. A plan or decision is regrettable if, for some future realization of uncertainties, we would prefer another plan. A plan that is preferred over all other plans for all possible futures is said to be robust or not regrettable.

A plan that is not robust may be almost robust (if it is regrettable for only a small minority of futures), robust with probability p (if the probability of an adverse future is $1-p$), practically robust (if the regret or preference for other plans in all adverse futures is minor), etc.

Exposure has to do with the futures in which a particular plan is regrettable. Exposure could be the set of futures for which a plan is regrettable, or the fraction of all futures for which it is regrettable, or the probability of a future occurring for which the plan is regrettable, etc.

Regret is the difference, measured in terms of some attribute, between the plan chosen and the plan that would have been preferred for a particular future, had we known it would occur. For transmission planning in Peru as formulated, regret may be measured in terms of HDN, MFI, NMO, or capital investment.

For some uncertainties probability models are available and useful. More often, “unknown-but-bounded” models are more appropriate, as we will show below [13]. A common error is to produce elegant results using probability models with guessed parameters, in a situation where the law of large numbers does not apply.

A hedge is a decision that reduces risk by increasing robustness or decreasing exposure or regret. For example, the proposed six-nation SIEPAC EHV line through Central America was almost robust, with exposure only if an international power market failed to develop. The Inter-American Development Bank (IDB) hedged by withholding financing until a market was created and functioning, up to the limits of the existing interconnections. The IDB even provided modest funding to help develop such a market [1].

The most common hedge is to delay deciding.

V. APPLYING CRITERIA UNDER UNCERTAINTY

A. System Studies

System studies are carried out to find attribute values for various combinations of plans and uncertainties.

Accurate forecasting of uncertainties is not the issue – relying on a point forecast is always wrong when uncertainties are significant. The issue is identifying ranges within which the uncertainties are highly likely to fall.

In principle, hundreds or thousands of *futures* – combinations of values of uncertainties – should be studied for each plan, in order to do proper risk analysis.

It is usually impractical to simulate so many cases using standard models. A few combinations of uncertainties and plans (“scenarios”) can be evaluated. These are called “knots.” Data expansion can be used to interpolate between the knots. This provides attribute estimates for many more scenarios than can be simulated directly [14].

B. Peru: Problem Formulation

For the Peruvian planning study (horizon year 2016), the authors identified four more or less coherent regions of the SEIN: Northern Peru, Central Peru (including Lima), Southeastern Peru, and Southwestern Peru. The key uncertainties were load growth and generation system development in each of these areas, and rainfall.

Many known hydro and thermal generation projects are under consideration for the ten year planning period. Not all of them will be built in the period considered – if they were, they would exceed the need under the most optimistic load growth projections. Table III lists possible values for generation in 2016 for each region. For purposes of simulation, MW of new generation was allocated to each known project, in proportion to the capacity of each project. This table includes existing as well as new generation.

The rows are not summed because it is not reasonable to suppose that the generation that materializes will be high in all regions, or low in all regions, etc. To some extent the uncertainty in generation is independent from one region to another, though the correlation coefficients are unknown and not meaningful.

TABLE III
GENERATION UNCERTAINTIES FOR PERU STUDY (MW, 2016)

	Northwest	Central	Southwest	Southeast
High	1305	5759	1702	665
	1248	5440	1510	722
Medium	1191	5121	1317	580
	1147	4871	1166	468
Low	1102	4620	1015	356

Table IV shows demand projections in the same regions. The Medium values are approximately the official forecasts. As with the generation uncertainty, the rows are not summed because load growth in one area is not necessarily correlated with load growth in another area.

TABLE IV
PEAK LOAD UNCERTAINTIES FOR PERU STUDY (MW, 2016)

	Northwest	Central	Southwest	Southeast
High	1115	4424	823	413
	974	3950	723	354
Medium	833	3475	623	294
	721	3060	559	254
Low	608	2645	495	214

Note that the ranges in Tables III and IV are large in percentage terms. For instance, the "high" values of peak loads are almost twice the "low" values for two of the regions. A common error in what is sometimes called "scenario analysis" is to assume that uncertainties are less than they really are. It is important that planners recognize extreme possibilities, even though they may be unlikely.

Peru has monthly stream flow history for about 40 years. The authors selected the three series of Table V for use in our studies. Note that, of the three major uncertainties, probability information is only available for hydrology.

At this point the "Curse of Dimensionality" is evident: there are more than 1 million combinations of the values in Tables III-V. How can so many futures be analyzed?

TABLE V
HYDROLOGICAL UNCERTAINTIES FOR PERU STUDY

	Year	Available Energy (GWh)	Probability of Exceeding
Wet	1973	20,061	2.4%
Median	1989	18,826	51.2%
Dry	2004	16,693	97.6%

In particular, how can they be analyzed for the 16 major transmission options listed in Table VI? Most of these options are somewhat independent of each other, though several represent stages in development sequences (for instance, "'B' is not useful unless 'A' is done first"), and the four Lima options are mutually exclusive.

TABLE VI
TRANSMISSION OPTIONS FOR PERU STUDY

Piura-Talara-Zorritos 220
Carhuaquero-Piura 220
Cajamarca-Carhuaquero 220
Cajamarca-Conga-Corona-Carhuaquero 220
Cajamarca-Caclic 138 & Caclic-Moyobamba 138
Huallanca-Cajamarca 220
Vizcarra-Huallanca 220
Marcona-Cotaruse 220
Marcona-Socabaya 220
Machu Picchu-Bambas-Cotaruse 220
Machu Picchu-Tintaya-Puno 220
Cotaruse AC/DC/AC + capacitors
Lima Ring
Lima Fuerte - Strong Ring
    Chilca-Planicie-Zapallal 500 (2 circuits)
Alt 1 - Moderate Ring 1
    Chilca-Planicie-Zapallal 220 (2 circuits)
    Chilca-Zapallal 500 (1 circuit)
Alt 2 - Moderate Ring 2
    Chilca-Planicie-Zapallal 220 (1 circuit)
    Chilca-Zapallal 500 (1 circuit)
Lima Light - Light Ring
    Chilca-Planicie-Zapallal 220 (2 circuits)

C. Peru: Knot Selection, Simulation, and Data Expansion

Some 23 knots were identified and simulated using a power flow program (to determine transfer capabilities) and a hydro-thermal production simulation program with a network model. The simulation outputs were values of HDN and MFI. Values of NMO were computed by hand. Capital investment was not sensitive to the uncertainties studied. The analysis considered real or uninflated costs whose uncertainties were considered inconsequential.

The knots were selected to permit interpolation over a multi-dimensional polyhedron whose axes are each area's uncertainties in future demand and generation.

For example Fig. 7 is a two-dimensional cut through an eight-dimension polyhedron that cannot be drawn. In Fig. 7, interpolation can be performed within the rhombus defined by the four extreme knots. Fig. 7 is a rhombus, not a square, because it is unlikely that "high" or "low" generation will develop in the Central region unless the load growth is also "high" or "low." The rhombus excludes regions that are not interesting while allowing more accurate interpolation in more interesting regions.

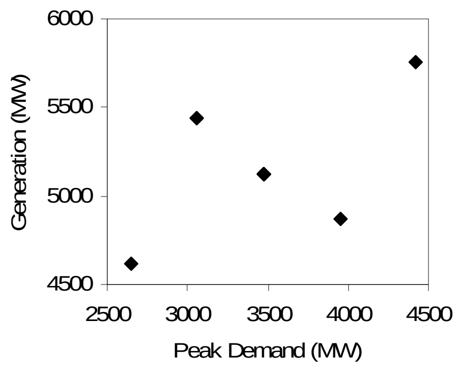

Fig. 7. Knots for generation and demand uncertainty, Central region.

Each knot was simulated for wet, median, and dry years. No interpolation was done for other hydro levels.

The 23 knots included "with" and "without" values of the various options. It was possible to model these with so few knots because many of the options and uncertainties are decoupled. Several could be simulated in the same run. For example, uncertainties and options in the south regions and uncertainties and options in the Northwest do not affect each other's HDN, MFI, and NMO.

With values for HDN and MFI computed for these knots, and with values of NMO computed by spreadsheets, the authors used a high-order piecewise-linear interpolation procedure [14] to estimate HDN, MFI, and NMO for many hundreds of futures, or combinations of values of the uncertainties. For convenience in comparisons to the criteria values described earlier, the results were expressed in hours/\$, MWh/\$, or W/\$.

For example, Fig. 8 shows the improvements in MFI and HDN for fifteen options. Ten of them did not affect these two attributes. (They may have affected NMO, but that isn't shown in Fig. 8. For brevity, we will discuss only HDN and MFI, though our study considered NMO as well.) In this nominal future (optimistic for hydro), three options satisfy the HDN criterion (100 h/\$ million) and three satisfy the MFI criterion (15 kWh/\$). Two Lima Ring options come close to satisfying the HDN criterion. The Machu Picchu-Tintaya-Puno and Huallanca-Cajamarca options satisfy both criteria shown.

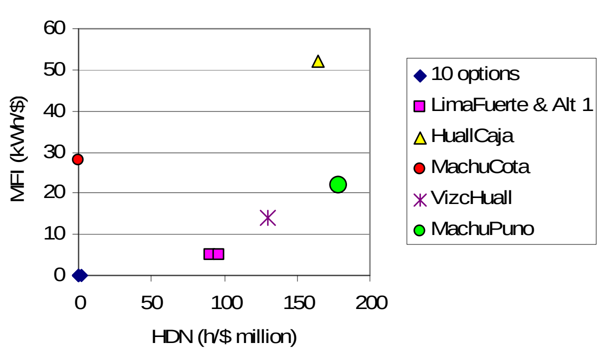

Fig. 8. Improvement in MFI and HDN, median demand and generation, wet hydrology. Each symbol represents one or more options.

D. Peru: Robustness

In Fig. 9, six options are evaluated for many futures, or realizations of uncertainties.

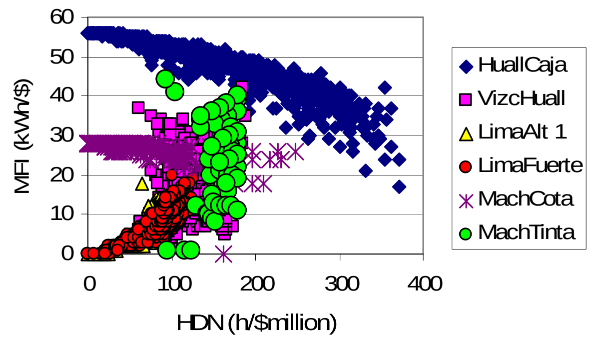

Fig. 9. Improvement in MFI and HDN for six options, evaluated for an average of 850 futures.

The Huallanca-Cajamarca project is robust. MFI is greater than 15 kWh/\$, or HDN is greater than 100 hours/\$ million, or both, for every future. This would be true even if the criteria values were not precisely 15 or 100.

The Machu Picchu-Tintaya-Puno project is essentially robust. It satisfies one or both criteria for all but two futures, where its HDN is 93 or 95, close enough to the criterion of 100.

The other projects are difficult to distinguish in Fig. 9 because they are obscured. Fig. 10 is de-cluttered: the Machu Picchu-Tintaya-Puno and Huallanca-Cajamarca options are removed and the scale is expanded. In addition, the Lima Fuerte option is removed: its values are very similar to those for Lima Alternative 1, and for our purposes are redundant. Fig. 10 shows that the Machu Picchu-Cotaruse option is robust, but the others are not.

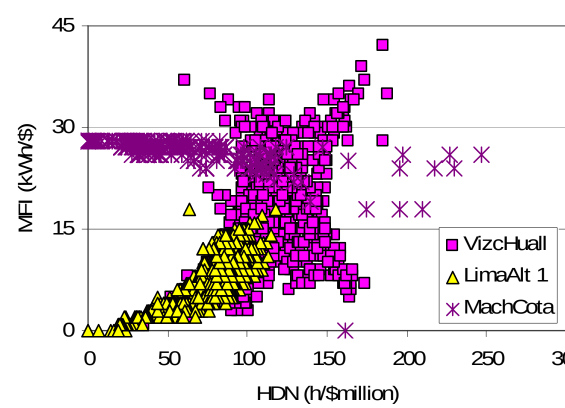

Fig. 10. Improvement in MFI and HDN, three options, for many futures.

In Fig. 8, ten options were found to have zero improvement in MFI and HDN and were excluded from the analyses in Figs. 8 and 9. Nonetheless, for one of them MFI and HDN exceeded the criteria for many futures (Fig. 11). Had the authors been satisfied with analyzing a nominal future and ignoring other possibilities, this important option would have been incorrectly discarded.

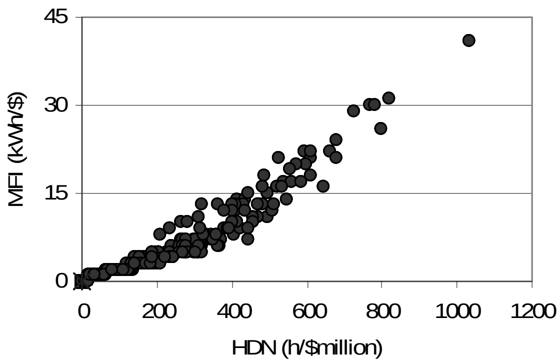

Fig. 11. Although for a nominal future it showed no improvement in MFI and HDN, for many futures the Cajamarca-Carhuaquero line satisfies the planning criteria.

E. Peru: Exposure

Although Figs. 9 and 10 show that the Vizcarra-Huallanca, Cajamarca-Carhuaquero, and Lima options are not robust, further analysis requires examining the data in greater detail. We will discuss the Lima options here.

Fig. 10 shows that for most futures (95% of them, in fact) the Lima Alternative 1 option does not satisfy either the MFI or HDN criteria. The Lima Fuerte option is more robust, but is still regrettable for 81% of the futures. Nonetheless, rejecting Lima Fuerte would be risky because for a significant number of futures one of the criteria is satisfied. If the project were not built, and if one of these futures materialized, the decision would be regrettable.

Analysis of the underlying data revealed that the Lima Fuerte option is regrettable unless there are heavy flows through Lima from south to north. These will occur if some combinations of the following conditions materialize: high development of new generation to the south of Lima, low development of new generation in the Northwest, and high growth of demand in the Northwest.

Choosing not to build the Lima Alternative 2 and Lima Light options is not regrettable in any future analyzed. The benefit/cost ratios embodied in the criteria are never satisfied.

F. Peru: Regret

The difficulty with the Lima options is due to congestion being possible and possibly significant in the part of the system that serves Peru's biggest load center. But the options for alleviating the congestion are so expensive that, except for a few futures, the planning criteria are not met by any of the four reinforcement options considered.

If Lima Fuerte is *not* built, and if one of many futures (more than 19% of them) materializes, the stakeholders will regret the congestion. Their regret will be measured directly in MFI or HDN, and less directly in possible redispatch costs or service interruptions or both.

If Lima Fuerte *is* built, and if one of many futures (but one of less than 81% of them) materializes, the stakeholders will regret having invested a significant amount in reinforcements that turned out not to be cost effective, according to the criteria. Their regret will be measured in dollars.

G. Peru: Hedge

Of course, the ideal solution in situations like the Lima problem would be to find cheaper reinforcements that would satisfy the criteria.

Another approach would be to say that the criteria, which were developed based on system-wide studies, need to be adapted for a large metropolitan area. This is done, for example, for the New York City area.

A third approach would be to determine whether the system has grown to the point where a higher-voltage overlay is appropriate. Such a decision is not necessarily based on normal planning criteria.

The following hedge, however, would reduce the regret associated with the Lima problem: reinforce the system with Lima Alternative 1, built for 500 kV but energized at 230 kV. If this turns out to be adequate, then the higher capital-cost regret associated with the more expensive 500-kV equipment would be avoided. If the system evolves to the point where the additional transfer capability is needed, then the 230-kV equipment could be changed out at a relatively low cost, avoiding the regret associated with high congestion.

VI. Conclusions

Transmission planning criteria can be set by analyzing the classical trade offs between such attributes as investment costs and measures of network congestion and reliability. Criteria are valuable because they allow the planner to avoid continually revisiting these difficult-to-quantify trade offs.

Transmission planning should and can recognize uncertainties and risk.

We have demonstrated the application of these concepts by describing elements of a recent transmission planning study for the Peruvian transmission system.

There are other ways of doing what this paper does. Some are emphatically wrong. We don't do them. Incorrect approaches include:

- *Monetarizing reliability, (expressing it in dollars)*, so as to create a "utility function" which can be optimized:

  J(planning option) = (cost of option) - k_1(NMO) - k_2(HDN) - k_3(MFI)

  The utility function approach is mathematically tidy, but we do not know k_1, k_2, and k_3, which express the societal value of reliability in dollars. For example, if electricity is unreliable, vaccine in a clinic may spoil and a child may die. What is the loss to society, *measured in dollars*, if the child would have become another Beethoven or Pasteur?

- *Forecasting the future, and then believing the forecast.* Some things are fundamentally unknown. It is necessary to project possible futures. But it is wrong to believe that a particular future will occur, and to base plans on this belief.

- *Basing plans on expected values of uncertainties.* This is a more scientific-appearing way, but not a more correct one, of choosing a future on which to base plans. In addition, when expected values are used, all risk information is lost.
- *Insisting on treating uncertainties probabilistically when their probabilities are unknown or irrelevant*, e.g., if the law of large numbers does not apply.

VII. Acknowledgment

We acknowledge the vision of Victor Ormeño, Manager of OSINERGMIN. He is profoundly affecting the development of the Peruvian electric system. This paper is based on work funded by OSINERGMIN. An earlier version was given in a seminar prior to the 2008 IEEE T&D conference in Bogota.

VIII. References

[1] T. De la Torre, J. W. Feltes, T. Gómez San Román, H. M. Merrill, "Deregulation, privatization and competition: transmission planning under uncertainty," *IEEE Trans. Power Systems*, vol. 14, no. 2, pp. 460-465, May 1999.

[2] E. O. Crousillat, P. Dörfner, P. Alvarado, and H. M. Merrill, "Conflicting objectives and risk in power system planning," *IEEE Trans. Power Systems*, vol. 8, no. 3, pp. 887-893, Aug. 1993.

[3] I.e., South Africa's "Freedom Charter" (1955) says that everyone has a right to electricity along with education, health care, housing, food, etc.

[4] P. Sandrin, Convener, "Techniques for Power System Planning under Uncertainty," CIGRE TF 38-05-08 Report, November 1998.

[5] M. V. F. Pereira, M. F. McCoy, and H. M. Merrill, "Managing Risk in the New Power Business," *Computer Applications in Power*, vol 13, no. 2, April 2000.

[6] F. C. Schweppe, H. M. Merrill, and W. J. Burke, "Least cost planning: issues and methods," *Proc. of the IEEE*, Vol. 77, No. 6, pp. 899-907, June 1989.

[7] F.C. Schweppe and H. M. Merrill, "Multiple objective trade off analysis in power system planning," 9th Power Systems Computation Conference, Cascais, Portugal, August-September 1987.

[8] C. Dortolina, R. Nadira, H. Fendt, N.J. Bacalao, and J. Di Bella "Strategic Assessment of Supply Options in Power Systems with Significant Supply Uncertainty", Proceedings of the Probabilistic Methods Applied to Power Systems Conf. (PMAPS-2004), September 12-16, 2004, Pages 867-872, Iowa State University, Ames, Iowa.

[9] L. K. Goel in *Encyclopedia of Science and Technology*, New York: McGraw-Hill, 2007.

[10] S. T. Lee, "For the Good of the Whole," *IEEE Pwr & Energy*, Vol. 5, No. 5, p. 28 (24-35), Sept/Oct 2007.

[11] See, for example, NERC transmission planning standards TPL-001 through TPL004, available: http://www.nerc.com/~filez/standards/Reliability_Standards_Regulatory_Approved.html.

[12] P. L. Bernstein, *Against the Gods*, New York: Wiley, 1998.

[13] F. C. Schweppe, *Uncertain Dynamic Systems*, Englewood Cliffs: Prentice-Hall, 1973.

[14] R. Mukerji, W. J. Burke, H. M. Merrill, and B. Lovell, "Creating data bases for power system planning using high order linear interpolation," *IEEE Trans. Power Systems*, Vol. 3, No. 4, pp. 1699-1705, November 1988.

IX. Biographies

Daniel Cámac (S'1992, M'1995) has a BSc in Electrical Engineering from UNCP-Peru and MSc in Electrical Engineering from PUC-Chile. He also obtained an MBA from ESAN-Peru. He is working towards a PhD in Electrical Engineering at PUC-Rio. He joined OSINERGMIN in 2000, where he worked in setting electrical tariffs, system planning studies and market power analysis. Recently, he worked in designing the bases and rules of the bidding process, and he participated in the design of the new regulatory transmission model in Peru. He was named Vice Minister of Energy and Mines in 2008.

Raúl Bastidas has a BSc in Electrical Engineering from UNCP-Peru and complete postgraduate studies in Public Service Regulation Master at PUCP-Peru. He has worked in electric power transmission since 1990. He has been working as specialist in OSINERGMIIN since 2003. His main occupation is performing technical analysis for tariff setting for electrical transmission utilities. He participated in activities to implement and update the regulatory framework for transmission and generation of electricity activities. He also participated in studies about planning of transmission network expansion.

Ramón Nadira (M'79, SM'91) is a Director with Siemens Energy, Inc., T&D Service Solutions. He is an Electrical Engineer with an MS in electrical engineering and applied physics, and a Ph.D. in systems engineering. His employment experience includes Scientific Systems, Inc., Simon Bolivar University, Power Technologies, Inc., Resource Management International, Inc., Stone & Webster Management Consultants, Inc., TRC Global Management Solutions, LP, and Siemens PTI. For over 24 years, Dr. Nadira has provided technical consulting services to electric utilities, independent project developers, and the financial community, in domestic and international assignments in the electric power sector.

Carlos Dortolina (S'89, M'91, SM'2001) is a Consulting Manager with Siemens Energy, Inc. – Power Technologies International ("Siemens PTI") in Houston, Texas. He is an Electrical Engineer with an MS in Electric Power Engineering, and an MBA in Economics. He has worked for Inelectra, Simon Bolivar University, Stone & Webster Management Consultants, Inc., TRC Global Management Solutions, LP, and Siemens PTI. Mr. Dortolina has specific international expertise in more than ninety projects in the energy sector, including feasibility studies and analysis of electric power systems. In addition, he has provided regulatory, privatization and/or restructuring support for electricity markets, as well as with the independent evaluation and review of electricity transmission & distribution ("T&D") companies. He is a member of Sigma Xi scientific honorary society.

Hyde M. Merrill (S'65, M'67, SM'81, F'93) is an electrical engineering graduate of the University of Utah and MIT (PhD 1972). He was with the American Electric Power Company for 7 years, spent a year at MIT on a visiting appointment, and worked for nearly 20 years at Power Technologies, Inc. He founded Merrill Energy LLC in 1998 to provide advanced capabilities in risk analysis and operations research to stakeholders in modern and traditional power markets. He is a member of the Eta Kappa Nu, Tau Beta Pi, and Sigma Xi honorary societies and is a registered professional engineer in New York.