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The Impact of Restructuring Policy Changes on Power Grid Reliability

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The Impact of Restructuring Policy Changes on Power Grid Reliability

Final Report

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Abstract

This paper outlines the results of a cooperative effort between Sandia National Laboratories, Associated Power Analysts, Inc. and Texas A&M University to characterize the impact of a changing regulatory environment on the reliability of customer electrical service. It was desired to assess the impact in as realistic an environment as possible. Due the availability of data the initial study centered on the electric power grid in Texas. Specifically, data from the Electric Reliability Council of Texas (ERCOT) for the 1997 operational year was used in the research. Based on geography and location of generation and transmission lines, ten basic areas were considered and each area was modeled as a single point generation and load. A number of restructuring scenarios were developed by researchers at Sandia National Laboratories and investigated by Associated Power Analysts using their N-Area Reliability Program (NARP). The present study is limited to an assessment of the adequacy aspects of reliability: sufficiency of installed generation and transmission capacity to satisfy the needs of all consumers in a steady-state sense. The results are, on one hand conservative in that they address only the impact of peak loading. Alternatively, they are optimistic in that the transmission lines are assumed to be in continuous operation. The major results of this study indicate that, in a new regulatory era, the reliability of customer service will be significantly impacted, possibly in a negative fashion, unless the effects of the ensuing economic pressures are understood and appropriate actions taken.

The Impact of Restructuring Policy Changes on Power Grid Reliability

INTRODUCTION

Electric energy service is characterized by two primary attributes: cost of energy service and quality or reliability of the service provided. The first attribute, cost, is well understood and easily measured and is the driver behind the various proposals to convert the electric power industry, at least in part, from a regulated monopoly to a competitive market. The second attribute, service quality or reliability, is also important as electric energy consumers have grown accustomed to a very high level of service quality and reliability and many industries are critically dependent on high service reliability in their operations. However, service reliability comes at a price which is not so well understood or very easily computed. Indeed, in regulated utilities operating in a vertically integrated mode there was no need to carefully understand the cost of reliability as a separate service. Therefore, there is now legitimate concern that service reliability will suffer under the economic pressures of price competition in competitive markets unless these effects are well understood and appropriate steps are taken to assure that economically and socially desirable levels of service reliability are maintained. The tension between the raw price of energy and service reliability is well illustrated by the June 1998 events in the Mid West in which energy transfers were curtailed in the interest of preserving the reliability of the overall system. Here the economic penalties of the curtailments were immediate and concrete while the reliability benefits of the curtailments are speculative and not well understood (Wall Street Journal, July 24, 1998).

The objective of this study is to estimate some of the more important effects of deregulation and a shift to competitive energy markets on service reliability at the bulk power level in a representative power pool. The power pool chosen for the study is the Electric Reliability Council of Texas (ERCOT) system and the base conditions studied are those which prevailed in 1997. The study has been conducted using a model, called NARP, for the computation of quantitative reliability indexes in the ERCOT system. The reliability of bulk-power systems is usually taken to have two aspects: adequacy and security. Adequacy deals with the sufficiency of installed generation and transmission capacity to satisfy the needs of all consumers in a steady-state sense while security deals with the ability of the system to survive transient upsets of various kinds. The present study is limited to an assessment of the adequacy aspects of reliability.

By way of background, an electric utility system is composed of three basic elements: the generation resources which produce electrical energy, the transmission network which transports the energy at high voltage from the generating plants to substations in proximity to consumers and also between areas and companies of the interconnected system, and the distribution system which carries the energy from the substations to the ultimate consumers. The generation resources together with the high-voltage transmission network constitute the bulk-power system and are the system elements most directly impacted by deregulation and are the subject of the present study. Of course all system elements contribute to system reliability or the lack thereof.

The bulk-power system primarily relates to overall system or regional service reliability while the distribution system relates to localized areas. The reliability of bulk-power systems has traditionally been very high so that widespread system or regional power outages have been rare and the large majority of power outages have been associated with distribution systems. However, bulk-power system outages, when they occur, and perhaps because they have been rare in this country, tend to have profound economic and social impacts, receive wide publicity and are widely studied as possible indications of serious underlying problems. Examples are the New York blackouts of the 1960's and 1970's, the 1996 West Coast system collapses and as cited above the Mid West power curtailments of June 1998.

NARP SYSTEM RELIABILITY MODEL

The system reliability model used in the studies is the N-Area Reliability Program (NARP). NARP was originally developed by Associated Power Analysts, Inc. in 1989 for ERCOT as a tool for the coordinated planning of the ERCOT bulk-power system. The model has since been modified and extended for study of deregulation-related issues in consultation with electric utility representatives.

NARP is a model for the calculation of reliability performance indexes in a multi-area interconnected power system. System components modeled are the individual generating units in each area and the transmission network which links the areas into an interconnected system. The model uses a Monte Carlo simulation approach to reflect the effects of chance events such as generator and transmission link failures as well as deterministic operating rules and policies. In effect, the Monte Carlo simulation procedure creates artificial histories of interconnected system operation from which the desired reliability performance indexes can be obtained.

Generating Units

The program is dimensioned for up to 20 different areas and up to 600 total generating units with no additional limitation on the number of generating units in each area.

- Generating unit forced outages are modeled considering either two or three-state unit models. Each unit state is characterized by a probability and a capacity.
- Generator planned outages are modeled deterministically with up to two planned outages per year for each generating unit. Planned outages can be pre-specified or automatically determined to levelize risk. A mixture pre-specified and automatically determined planned outages is permitted.
- Generating unit capacity ratings can be specified on a seasonal basis, four seasons per year, or held constant throughout the year. It is assumed that season dates are the same in all areas of the system.
- The time to start and load the unit is specified as a function of the time since the unit was last operated.

Transmission Network

The transmission network of the interconnected system is modeled as an equivalent network of transmission links between system areas. Each area is assumed to have a single transmission bus to which all transmission links, generators and loads are connected. That is, the model does not directly consider the effects of transmission limitations within an area. Further, physical transmission lines between areas are not explicitly modeled but are reflected in the equivalent transmission links between areas. Thus, a first step in the use of the NARP model is the development of an appropriate transmission network equivalent which yields the transfer capability between each pair of areas (considering physical lines between areas as well as physical lines internal to areas which may limit inter-area transfers) together with the admittances of the equivalent links.

The NARP model is designed to model transmission network equivalents reflecting both available transmission transfer capability (ATC) and total transfer capability (TTC). The model reflecting ATC is created assuming first contingency conditions (outage of single most limiting facilities) while the TTC model assumes that all lines are in service.

Flows in the equivalent transmission network are modeled using a d-c load flow approach. That is, only real power flows are modeled and var flows and voltage conditions are not considered.

Key features of the transmission network model are outlined as follows.

- Each transmission link can be modeled as a multi-state link with up to six capacity states. Each capacity state is characterized by a probability and an admittance.
- Transmission link capacities for each capacity state can be specified as a function of the direction of power flow in the link. This feature allows the user to reflect transmission constraints internal to areas or other constraints not explicitly considered in the network model.
- Transmission link capacities can be modified by input data factors to reflect the dependence of link capacities on the statuses of specified generating units. This feature allows the user to model internal transmission constraints arising from the loss of specified generating units. Thus, the use of this feature allows partial recognition of the effects of internal transmission limitations without explicit modeling of the internal transmission network.
- Constraints on the algebraic sum of flows in transmission links terminating in each area can be specified. This feature enables the user to further constrain the total imports or exports to or from an area where that may be appropriate.

Loads

The load model for each area consists of an 8760-hour load cycle for firm loads and a similar load cycle for interruptible loads. These load cycles are created from specified per unit load cycles and annual peak loads.

Load forecast uncertainty can be modeled if desired. This is done assuming that load forecast errors are normally distributed with zero mean and specified standard deviation. It is assumed that the defined load forecast error distribution, in terms of percentage of load, applies for all hourly loads of a load cycle. Further, it is assumed that all area load forecast errors are perfectly correlated so that all area loads scale up and down together in response to load forecast errors.

Contracts and Entitlements

The program is capable of modeling firm contracts for power interchanges between all pairs of areas. These contracts are specified by the user and can be modified as often as daily.

Percentage entitlements to the available capacity of jointly-owned generating units or other out-of-area units such as cogeneration units can be specified. These entitlements create area interchanges which are automatically modified as unit available capacities change.

Operating Reserve Requirements

Operating reserve requirements are modeled as a specified MW amount, 2300 MW in ERCOT at present. A specified percentage of the operating reserve requirement can be met by interruptible load and the balance must be satisfied by the commitment of generation resources. At present 25% or 575 MW of the operating reserve in ERCOT can be satisfied by interruptible loads.

Generating Unit Commitment

The NARP program is capable of modeling two different classes of generating unit commitment policies or scenarios. These are outlined as follows.

- All generating units are assumed available to operate on a daily basis unless in a state of forced or planned outage. Here, in effect, all units are assumed to be in continuous operation and readily available to satisfy load demands within the constraints which may be imposed by transmission limitations. In reality not all units operate continuously for economic reasons, but it is assumed that all units can be brought on line as needed and without delay. This is the traditional assumption made in the past for reliability studies for planning purposes.
- The second set of commitment policies consider the commitment of generating units daily to satisfy load demand plus operating reserve requirements. The units which are assumed available to serve if needed are the units committed that day plus units which can be started quickly enough to be brought on line within about four hours. Three different unit commitment scenarios are possible.
    1. Generating units are committed from a pool-wide unit commitment priority list to satisfy pool daily peak load plus the operating reserve requirement, but without regard for area protection or transmission limitations. This scenario can be regarded as the result of pure price competition with no allowances for the maintenance of reliability.
    2. Generating units are committed from company-specific unit commitment priority lists to satisfy area daily peak loads while considering firm load contracts between areas and entitlements to the outputs of out-of-area generating units. Generating units are also committed to satisfy specified area operating reserve requirements. The unit commitment schedule is checked and

adjusted as necessary to satisfy the constraints of available transmission transfer capability (ATC). This scenario is intended to simulate current practice (regulated operation with limited price competition).

3. Generating units are committed from a pool-wide unit commitment priority list to satisfy pool daily peak load. Additional units are then committed to satisfy operating reserve requirements within the constraints imposed by available transmission transfer capabilities (ATC). This scenario is intended to simulate conditions expected to prevail under deregulation with unit commitment schedules and inter-area transfers constrained by ATC rules under the control of an Independent System Operator (ISO).

Reliability Indexes

The following reliability indexes can be computed for each area as well as for the interconnected system as a whole.

- LOLE The expected number of daily peak load loss events per year.
- HLOLE The expected number of hours of load loss per year.
- EUE The expected unserved energy per year in MWh
- XLOL The expected magnitude of a load loss event in MW

As an option, indexes can be computed for daily peak loads only. If this option is chosen, which substantially speeds up the simulation, only the LOLE and XLOL indexes are computed.

Each of the above indexes are also separated into two components: "generation constrained" and "transmission constrained" as a further aid to analysis. The "generation constrained" indexes reflect those load loss events which are due to lack of available generating capacity and are defined as loss events for which the available generating capacity in the interconnected system is less than the interconnected system load. Similarly, "transmission constrained" indexes reflect those load loss events which are due to lack of available transmission transfer capability and are defined as loss events for which the available generating capacity in the interconnected system is greater than the interconnected system load.

The above reliability indexes are expected values and as such indicate the long-run-average reliability which can be expected. These indexes do not, therefore, indicate the year-to-year or event-to-event variation in reliability performance which can be experienced. This additional information is, however, available from the Monte Carlo simulation. Thus, NARP provides the following additional output:

- Probability distribution of number of daily peak load loss events per year
- Probability distribution of number of hours of load loss per year
- Probability distribution of unserved energy per year

The NARP model is capable of modeling two different policies of cooperation among areas in the event of emergencies. These are called "loss sharing" and "no-loss sharing" policies. In no-loss sharing, areas with positive margins assist areas with negative margins to the extent possible within transmission constraints, but without sharing in any load loss. In loss sharing, all areas attempt to minimize load loss in the interconnected system by sharing resources even at the expense of some load shedding in areas with positive margins. Reliability at the system or pool level is improved by a policy of loss sharing since this policy permits greater flexibility in use of resources to maximize flows into areas experiencing shortages. In both policies NARP optimizes the use of all resources within the constraints imposed to minimize load loss events and thus simulates maximum cooperation within the stated policy to minimize load loss events.

THE ERCOT SYSTEM

The interconnected system which has been studied is the Electric Reliability Council of Texas (ERCOT) system. The system has been modeled as a ten-area interconnected system with the ten areas representing the major load and generation concentrations of the system as shown in Figure 1.

The total installed generation capacities and annual peak firm and interruptible loads for each area and for the system as a whole as used in the study are summarized in Table 1. The generation capacities are those that prevailed in 1997 and the firm peak loads are those that were projected for 1997 according to ERCOT records. The interruptible loads are those forecasted for 1998. The generation reserve in the pool is 19.9 per cent based on total installed capacity and firm loads only and 13.2 per cent considering interruptible loads also.

The generation fleet in ERCOT in 1997 and as used for the study consisted of 4 nuclear units, 27 coal or lignite units, 190 gas units, 51 combustion turbine units, 20 hydro units, 1 wind unit, 33 cogeneration units, 1 equivalent unit representing an aggregate of diesel units and 1 equivalent unit representing d-c ties to the Southwest Power Pool.

The time to start and load a generating unit is, in general, a function of the time since the unit was last operated. The rules regarding the abilities of units to start and serve load on a day were determined in consultation with utility personnel within ERCOT and are believed to represent reasonable approximations to the complex factors influencing unit starting times. The following rules were used in the study.

- Nuclear units- unavailable on a day unless committed that day.
- Coal and lignite units- unavailable on a day unless committed that day.
- Gas units greater than 400 MW (except for two peaking units)- unavailable on a day unless committed that day.
- Gas units less than 400 MW (and two larger peaking units)- unavailable on a day if not operated within preceding three days.
- Combustion turbine units, hydro units and d-c tie equivalent unit- available any day whether committed that day or not.
- Cogeneration units- regarded as base loaded and committed every day.

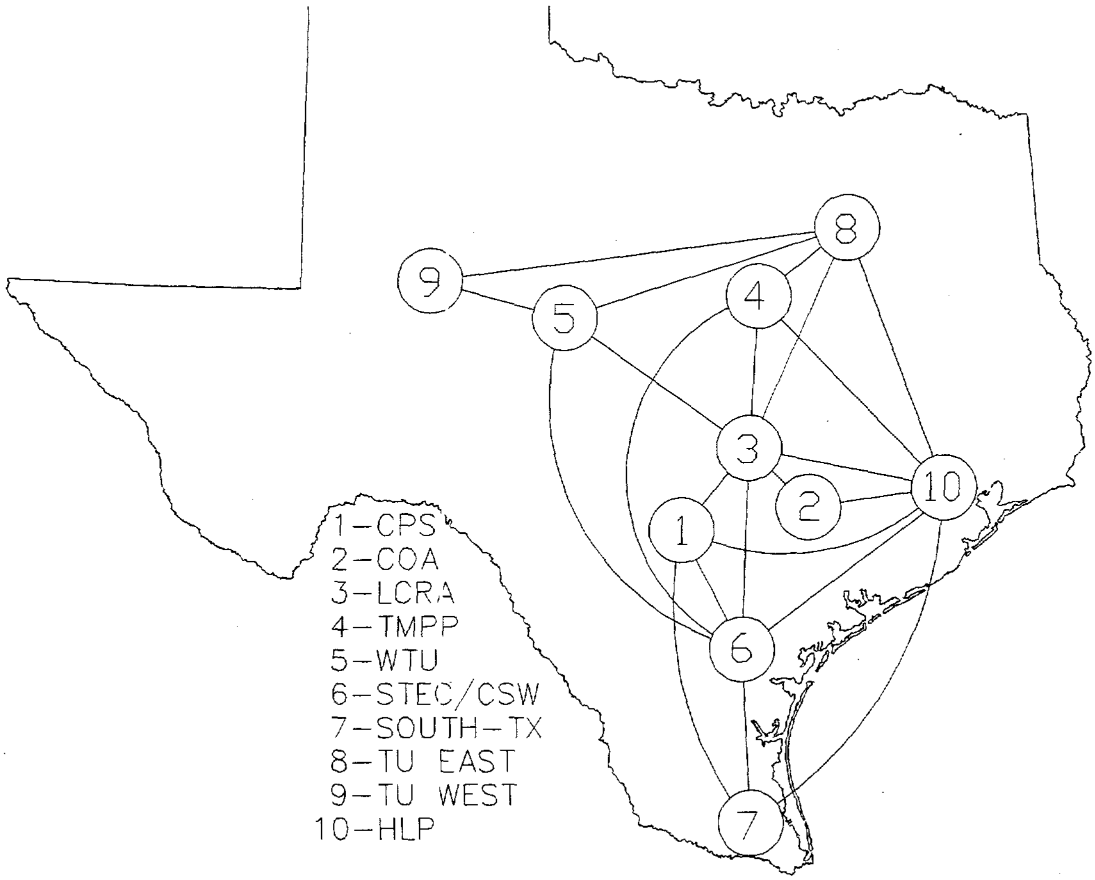

Figure 1. The ERCOT System

Table 1
Study Generating Capacities and Loads

Area	Capacity, MW	Firm Peak Load, MW	Interruptible Load, MW Winter	Interruptible Load, MW Summer
1	4515	3412	13	13
2	2459	1879	0	0
3	2347	2132	109	109
4	2739	2267	32	32
5	1688	1336	118	118
6	1721	1168	415	415
7	3114	2970	0	0
8	21151	18377	785	785
9	2468	1489	403	403
10	14008	11982	605	902
Total	56390	47012	2480	2783

The transmission network equivalents used in NARP were derived from the full ERCOT a-c load flow model. Transmission equivalents were found for both the available transfer capability conditions (ATC) assuming critical lines out of service and also for total transfer capability conditions (TTC) assuming all lines in service. Tables 2 and 3 show the inter-area transfer capabilities for each of these two cases.

Table 2
Available Transfer Capabilities (ATC), MW

To Area

From Area	1	2	3	4	5	6	7	8	9	10
1	X	-	305	-	-	186	239	-	-	0
2	-	X	65	-	-	-	-	-	-	0
3	303	1234	X	0	59	0	-	80	-	110
4	-	-	160	X	-	0	-	585	-	743
5	-	-	1	-	X	64	-	493	0	-
6	67	-	188	277	15	X	665	-	-	55
7	327	-	-	-	-	797	X	-	-	0
8	-	-	434	1422	213	-	-	X	55	716
9	-	-	-	-	496	-	-	366	X	-
10	818	327	54	34	-	392	582	16	-	X

Table 3
Total Transfer Capabilities (TTC), MW

To Area

From Area	1	2	3	4	5	6	7	8	9	10
1	X	-	415	-	-	219	326	-	-	0
2	-	X	567	-	-	-	-	-	-	145
3	1604	2215	X	0	282	260	-	1151	-	227
4	-	-	193	X	-	151	-	1097	0	1052
5	-	-	61	-	X	128	-	1017	0	-
6	329	-	391	468	151	X	978	-	-	351
7	726	-	-	-	-	944	X	-	-	272
8	-	-	1565	3704	745	-	-	X	72	2126
9	-	-	-	-	589	-	-	463	X	-
10	1608	458	208	718	-	790	817	1071	-	X

The available transfer capabilities (ATCs) of the network are used in the unit commitment process to limit planned inter-area transfers to conservative values. These conservative values, which provide margins for transmission failures, have been determined to be prudent by the ERCOT ISO and are commonly used in scheduling planned interchanges in power pools. The total transfer capabilities (TTCs) of the network give the transfers which are possible without line overloads assuming all transmission lines are in service. These TTC values represent flow level limits which leave no margin for line failures and which may or may not be used by the ISO in scheduling emergency transfers depending on operating policy.

For the purposes of computing reliability indexes, we have assumed that transmission lines do not fail. This assumption is optimistic in that lines do fail although at a rate much lower than that of generating units. Past experience in reliability studies of interconnected systems is that the primary effect of the transmission network is captured using fully available capacities since the failure rates of lines are low.

Entitlements to the outputs of out-of-area utility-owned units, either solely or jointly owned, as well as to contracted outputs of out-of-area cogeneration units exist in ERCOT. These entitlements create unit-dependent area interchanges which for the study are shown in Table 4. Firm contract area interchanges also exist. The firm contract area interchanges in ERCOT for 1997 and 1998 are as shown in Tables 5 and 6.

Table 4
Unit-Dependent Interchanges

From Area	To Area	MW
3	2	620
5	6	14.8
5	7	109.7
6	4	88
8	4	15
8	10	1740
10	1	700
10	2	400
10	4	88
10	6	177.5
10	7	452.5
10	8	410

Table 5
Firm Contract Interchanges for 1997

From Area	To Area	MW
2	3	6
3	2	3
3	5	28
3	6	29
4	5	27.5
4	8	42.5
6	3	3
6	8	43
10	3	75
10	6	30

Table 6
Firm Contract Interchanges for 1998

From Area	To Area	MW
1	4	50
2	4	100
4	6	100
6	3	2
6	4	88
6	7	88
8	3	25
10	3	437
10	4	82
10	6	349

The operating reserve requirement enforced in ERCOT at the present is 2300 MW. Up to 25 per cent of this reserve requirement, or 575 MW, can be satisfied by interruptible load. Thus, for the study, 2300-575=1725 MW of the reserve requirement is met by the commitment of generating capacity and the remaining 575 MW is assumed to be met using interruptible load.

The NARP program is capable of modeling two policies of inter-area assistance during capacity shortages. These are loss sharing and no-loss sharing. Under loss sharing all areas are assumed to cooperate to minimize pool load loss even at the expense of some area load loss while under no-loss sharing areas are assumed to share surplus capacity only. A review of the present ERCOT ISO operating rules indicates that the model assuming no-loss sharing most accurately simulates ERCOT at present as far as capacity adequacy is concerned.

STUDIES AND RESULTS

Five sets of cases have been studied. The first set of studies, called the base cases, consider the policies believed to best simulate the present operation of the ERCOT system and the four different modes of unit commitment which are possible in the NARP model, namely:

- All generating units are assumed to be committed (the classical planning assumption).
- Generating units are committed on a daily basis to satisfy area loads and operating reserve requirements from area unit commitment priority lists. This mode of operation corresponds to the past, and substantially the current, practice.
- Generating units are committed on a daily basis to satisfy pool loads and operating reserve requirements from a pool-wide unit commitment priority list without consideration of any transmission constraints. This mode of operation is intended to simulate pure price competition without any limitations on transmission network loading to assure reliability in system operation.
- Generating units are committed on a daily basis to satisfy pool loads and operating reserve requirements from a pool-wide unit commitment priority list, but with transmission loading constraints simulating actions of the ISO to assure that

transmission constraints are not violated. This mode of operation is intended to simulate deregulated conditions in which generators of energy compete for load without consideration of transmission wheeling charges, or assuming a postage-stamp wheeling charge prevails, within the reliability-enhancing constraints imposed by the ISO. This mode of operation may most closely simulate deregulated operations in ERCOT.

The base case studies have all been made assuming:

- Reliability indices are calculated considering firm loads only. That is, it is assumed that the shedding of interruptible loads does not constitute a load loss for reliability purposes. This is the classical approach to reliability evaluation in bulk power systems.
- The ERCOT system operates in a no-loss sharing mode as regards cooperation during capacity shortage emergencies. This is the mode of cooperation in ERCOT at present.
- Transmission network flow limitations for purposes of unit commitment and planned transfers between areas reflect available transfer capabilities (ATCs), but flows under capacity emergency conditions are limited only by total transfer capabilities (TTCs). That is, no transmission capacity is held in reserve during capacity emergencies. This operation policy simulates ERCOT ISO policy.
- Firm contract interchanges between areas are those shown for 1997.

The second set of studies replicates the base case studies except that shedding of interruptible load is now considered a load loss for the purpose of computing reliability indexes. These cases can also be viewed as a conversion of interruptible load to firm load. There is some reason to believe that industries which presently have interruptible load tariffs will convert to firm load tariffs if loads are curtailed more often than in the past- a likely circumstance under deregulation.

The third set of studies evaluates the effect of a changed policy of transmission utilization which may arise under deregulation. Here we assume that ATC limits are enforced both for purposes of unit commitment and planned transfers between areas and for unplanned transfers during capacity shortage emergencies. This is in contrast to the present practice of using TTC limits during emergencies. We believe there may be a trend to the more conservative policy under deregulation as utilities seek to preserve service within areas by taking additional steps to avoid system collapses.

The fourth set of studies evaluates the effect of a changed policy of cooperation during capacity emergencies. ERCOT presently operates under a no-loss sharing policy of cooperation during capacity shortages. However, in the past, we believe the industry generally may have operated under a policy more nearly approximating a loss sharing policy in which all utilities cooperated fully in attempts to minimize pool load shedding. If this was so in the past, it evidently will not be so in the future as utilities' incentives to cooperate are reduced under deregulation. Thus, this set of studies compares reliability under loss sharing and no-loss sharing modes of cooperation in emergencies.

The fifth set of studies considers the reliability implications of changes in firm contract interchanges between areas. Depending on the future form of deregulation in Texas, the location of new generating units and future policies as regards use of the transmission network (will planned transfers be given priority over unplanned, spot market, transfers), the number and magnitude of firm contract interchanges will expand or contract.

Base Cases

Base case results are summarized in Table 7. Here reliability is measured in terms of LOLE, the expected number of days per year on which some firm load must be shed. Operating modes studied are abbreviated and defined as follows:

- Classical- All units are assumed to be committed
- Company- Units are committed on a company or area basis
- Pure Pool- Units are committed on a pool basis without regard for transmission constraints
- Modified Pool- Units are committed on a pool basis, but with observance of transmission constraints

Table 7
Base Case Area and Pool Reliability, LOLE

Area	Classical	Company	Modified Pool	Pure Pool
1	0.00	0.04	0.02	0.04
2	0.00	0.04	0.02	0.04
3	0.00	0.01	0.00	0.00
4	0.72	0.32	2.17	0.18
5	0.00	0.01	0.05	0.07
6	0.00	0.02	0.92	5.75
7	0.00	0.06	0.45	6.04
8	0.11	0.74	2.08	0.27
9	0.04	0.10	0.13	0.10
10	0.12	1.13	0.80	0.59
pool	0.97	2.13	5.53	11.66
% trans. Caused	100%	87.8%	97.3%	98.8%

A number of observations can be made from the data displayed in Table 7.

- Considering reliability at the pool level, reliability decreases (LOLE increases) under deregulation. The amount of LOLE increase form past practice to that under deregulation depends on the models thought to be most representative. If past practice is modeled most accurately by the "company commitment" model and deregulated operation is modeled most accurately by the "modified pool commitment" model, then reliability is shown to be degraded by a factor of about 2.6 in moving to deregulation. The factor of degradation may be larger, up to about 12, if the classical planning assumptions regarding unit availability on a daily basis are more accurate for the past and if the ISO relaxes transmission constraints governing unit commitment and planned transfers between areas in the future.

- The change in area reliability under deregulation is not uniform. Some areas are seen to benefit while others suffer reliability degradation under deregulation. This is so because of the non-homogeneous nature of the ERCOT pool- not all areas have the same mix of generating resources, the same installed reserve levels or the same transmission network tie capacities.
- Transmission network constraints account for a large majority of the load loss events in ERCOT. Further, transmission network constraints are seen to constitute an increasing percentage of load loss events under deregulation. This is not surprising since the ERCOT transmission network was not originally designed for the level of inter-area transfers which will occur under deregulation. Clearly, reliability in ERCOT would greatly benefit from an increase in transmission network capacity.

Interruptible Load Conversion Cases

An obvious trend in ERCOT and elsewhere is the increasing number of curtailments of interruptible loads as authorized under their tariffs. In the past interruptible loads were rarely interrupted and so the cheaper rates offered for such loads represented good values for some industries. We believe it is likely under deregulation that industries will find that interruptible load tariffs are no longer the bargain they once were and that therefore many interruptible loads will become firm loads. This conversion of loads will have the effect of increasing the loads used for reliability assessment without increasing the generating capacity which must be committed to satisfy load and operating reserve requirements. Obviously, reliability will decline when this takes place.

Table 8 shows results when the base case conditions are modified to assume that 100 per cent of interruptible load has been converted to firm load, or alternatively, to assume that the shedding of interruptible load constitutes a load loss event just as does the shedding of firm load. Similarly, Table 9 shows results assuming that 50 per cent of interruptible load has been converted to firm load.

Table 8
100 Per Cent of Interruptible Load Used in Reliability Calculation, LOLE

Area	Company	Modified Pool	Pure Pool
1	3.90	1.14	1.78
2	3.70	2.86	5.44
3	0.80	0.43	0.56
4	2.90	9.29	5.89
5	1.20	2.00	3.44
6	1.30	15.43	49.67
7	5.40	5.57	30.22
8	13.10	15.43	7.56
9	3.30	3.64	3.33
10	11.40	6.29	6.00
pool	22.30	38.71	70.78
% trans. Caused	45.3%	76.8%	86.6%

Table 9
50 Per Cent of Interruptible Load Used in Reliability Calculation, LOLE

Area	Company	Modified Pool	Pure Pool
1	0.56	0.41	1.38
2	0.60	0.46	0.90
3	0.11	0.06	0.14
4	0.14	1.52	0.19
5	0.12	0.36	0.52
6	0.18	2.38	14.90
7	0.54	3.55	22.29
8	3.39	7.90	1.67
9	0.89	0.89	0.90
10	3.38	3.51	2.52
pool	6.96	16.81	36.14
% trans caused	72.1%	90.1%	95.4%

The following observations can be made regarding the cases in which some or all interruptible load is considered when calculating the reliability indexes.

- Economic forces under deregulation are likely to cause a number of industries which have opted for interruptible load rates in the past to shift to firm load rates in the future. This shift in load treatment will have the effect of increasing the amount of load that must be considered for reliability purposes (assuming that only firm load is considered for reliability purposes as has been traditional). Also, a shift in load treatment will effectively reduce operating reserves in that, at present, interruptible loads are considered when committing units, but are not also considered when computing reliability indexes. Therefore, assuming that only generating units which are committed or which can be started quickly are available to serve, reliability is bound to suffer.
- The results of Tables 8 and 9 show substantially higher values of LOLE when some or all interruptible loads are included when computing reliability. If no interruptible loads are considered when calculating reliability indexes and if the "company unit commitment mode" is considered as representative of past practice and if 100 per cent of the interruptible load converts to firm load under deregulation, then ERCOT pool-level reliability under deregulation is likely to be degraded by a factor of at least a factor of 38.71/2.13=18.2. Similarly, if half the interruptible load converts to firm load, reliability under deregulation is likely to be degraded by a factor of 16.81/2.13=7.9.
- Results again show the predominant effects of transmission capacity shortages on reliability in the ERCOT pool. However, it is also clear that transmission bottlenecks are proportionately less of a factor and generation capacity

shortages more of a factor in load loss events as the effective load used for reliability assessment is increased.

- The results of Table 8, together with Table 7 results, can also be interpreted to give the expected number of times per year that interruptible loads are curtailed. The differences in LOLE values between Tables 7 and 8 are the expected number of interruptible load curtailments per year. Thus, the expected number of interruptible load curtailments per year at the pool level for past practice (company commitment mode) is 20.17 while the expected number of curtailments per year assuming the "modified pool commitment" mode of operation under deregulation and also assuming no interruptible loads have been converted to firm loads is 33.18. This increase in the number of interruptible load curtailments under deregulation is a primary reason for the expected shift of interruptible loads to firm loads.

Transmission Policy Change Cases

The present policy in ERCOT is to schedule all planned inter-area transfers so as to be within conservative ATC limits. This is also the general policy followed in other power pools. Scheduling of planned transfers within the conservative (first contingency) ATC limits means that the system has a transmission transfer capability margin and therefore a reasonable ability to deal with unforeseen equipment outages and other emergencies. Under actual emergency conditions ERCOT presently allows full use of all available transmission transfer capacity and allows transfers up the total transfer capabilities (TTCs) of the network. This is the policy which has been modeled in the base cases and the other foregoing cases.
Recently, however, there have been cases (June 1998 in the Midwest) in which loads were shed because system operators continued to enforce ATC limits during conditions regarded, by some at least, as emergency conditions. This illustrates the tension existing between the desire to have access to the full capacity of the transmission network for economic transfers and the desire to maintain the reliability of the system. Therefore, it may be some pools will essentially enforce ATC limits at all times short of total system jeopardy.

Tables 10 and 11 show the effects of using transmission ATC limits for reliability calculations (during emergencies) as well as for purposes of unit commitment and planned transfer scheduling. These cases consider the "modified pool" mode of unit commitment only, the mode considered to best simulate deregulated operations. These cases also use the 1998 firm contract interchanges and assume a no-loss sharing policy of cooperation during emergencies.

The results of Tables 10 and 11 clearly show that reliability in terms of LOLE, the expected number of daily peak load loss events per year, would be severely degraded if the full available capacity of the transmission network was not utilized in time of emergency. It is probably true, however, that the risk of complete system collapse would be minimized by holding some transmission capacity in reserve during the more routine emergencies.

Table 10
Reliability Based on Firm Load Only

Area	ATC Used for Emergencies	TTC Used for Emergencies
1	77.60	0.06
2	60.00	0.04
3	2.40	0.00
4	79.20	0.90
5	1.20	0.05
6	32.60	0.74
7	79.20	0.75
8	15.20	3.50
9	0.20	0.13
10	17.20	1.31
pool	216.40	6.74
% trans caused	99.8%	97.2%

Table 11
Reliability Based on Firm Load Plus 100 % of Interruptible Load

Area	ATC Used for Emergencies	TTC Used for Emergencies
1	118.60	2.80
2	78.60	2.60
3	6.20	0.20
4	78.60	2.40
5	10.80	2.20
6	143.00	17.40
7	192.40	10.80
8	42.20	19.00
9	3.80	3.20
10	41.40	11.40
pool	301.20	46.00
% trans caused	97.0%	78.7%

Emergency Cooperation Policy Cases

The cases shown here compare reliability achieved assuming a policy of no-loss sharing during emergencies and a policy of loss sharing during emergencies. These cases consider the "modified pool" mode of unit commitment, the use of TTC transmission limits during emergencies and use the 1998 firm contract interchanges. Results are summarized in Tables 12 and 13.

Table 12
Reliability Based on Firm Load Only

Area	Loss Sharing Policy	No-Loss Sharing Policy
1	0.01	0.06
2	0.01	0.04
3	0.02	0.00
4	0.41	0.90
5	0.05	0.05
6	0.38	0.74
7	0.10	0.75
8	0.09	3.50
9	0.08	0.13
10	0.18	1.31
pool	1.04	6.74
%trans caused	85.6%	97.2%

Table 13
Reliability Based on Firm Load Plus 100 % of Interruptible Load

Area	Loss Sharing Policy	No-Loss Sharing Policy
1	2.47	2.80
2	2.31	2.60
3	2.37	0.20
4	10.40	2.40
5	2.39	2.20
6	11.40	17.40
7	3.32	10.80
8	3.74	19.00
9	6.61	3.20
10	6.48	11.40
pool	24.98	46.00
%trans caused	62.2%	78.7%

Results show that reliability at the pool level is substantially higher under a loss sharing policy of cooperation. The reliability of individual areas may be higher or lower under a policy of loss sharing.

Firm Contract Interchange Cases

At this point in time it is not clear whether the number and magnitude of firm contact interchanges between areas in ERCOT will increase or decrease under deregulation. This depends on the form of retail deregulation eventually adopted in Texas and on the rules adopted as regards the priority of use of transmission capacity. If a California-like arrangement is adopted and if long-term contracts are not given priority over spot sales in use of the available transmission capacity, then there will be few firm contract transfers. Alternatively, if the present bilateral contract approach to transfers is continued and if long-term contracts are given priority in use of the network, then the number and magnitude of firm contract transfers is likely to increase.

The impact on reliability of a firm contract is very much a function of the particular areas involved, the network topology and capacity and the mix of generating units in the areas involved. Thus, it is difficult to create hypothetical future firm contracts which are meaningful. Accordingly, we have limited our study of the effects of firm contracts to three cases: the contracts which existed in 1997, the contracts which exist in 1998, and a hypothetical case assuming zero contracts. Results are shown in Tables 14 and 15 for the conditions we believe most likely to prevail under deregulation in Texas, namely: the "modified pool" mode of unit commitment, the no-loss sharing mode of cooperation during emergencies and the use of TTC limits on transmission flows during emergencies.

Table 14
Effects of Firm Contract Interchanges
Modified Pool Mode of Unit Commitment
Firm Loads Only Used for Reliability Calculations

Areas	1997 Firm Contracts	1998 Firm Contracts	Zero Firm Contracts
1	0.02	0.06	0.03
2	0.02	0.03	0.03
3	0.00	0.00	0.00
4	2.17	0.90	2.95
5	0.05	0.05	0.05
6	0.92	0.74	1.05
7	0.45	0.75	0.59
8	2.08	3.50	3.22
9	0.13	0.13	0.10
10	0.80	1.31	0.83
pool	5.53	6.74	7.67
%trans caused	97.3%	97.2%	97.7%

Table 15
Effects of Firm Load Interchanges
Modified Pool Mode of Unit Commitment
Firm Loads Plus 100% of Interruptible Loads Used for Reliability Calculations

Areas	1997 Firm Contracts	1998 Firm Contracts	Zero Firm Contracts
1	1.14	2.80	1.14
2	2.86	2.60	3.00
3	0.43	0.20	0.86
4	9.29	2.40	8.57
5	2.00	2.20	2.57
6	15.43	17.40	19.71
7	5.57	10.80	5.86
8	15.43	19.00	18.57
9	3.64	3.20	3.00
10	6.29	11.40	7.14
pool	38.71	46.00	45.29
%trans caused	76.8%	78.7%	77.9%

The reliability effects of the firm contact interchange variations studied are shown to be minimal at the pool level, but substantial for some areas. Evidently, the reliability effects of firm contracts are very location-specific and must be examined for specific proposed contracts.

GENERAL CONCLUSIONS

It seems possible to draw a number of general conclusions from the study.

- Deregulation is likely to cause substantial reductions in service reliability at the bulk system level of ERCOT. Reliability is most likely to degrade by a factor of 2.6 at the pool level, but would degrade by much larger factors if existing interruptible loads are converted to firm loads or if more conservative rules are adopted for the managing of network flows during "minor" emergencies. The effects on reliability in particular areas are divergent and area reliabilities only roughly track that at the pool level.
- Deregulation will greatly increase power transfers between areas and change the pattern of inter-area transfers and the network will be utilized in a way not envisioned in its design. In ERCOT a large majority of system capacity shortfall events are the result of inadequate transmission capacity. Therefore, it seems most likely that the reliability of the ERCOT system as operated under deregulation could be improved substantially by judicious strengthening of the transmission network.
- It seems likely that many interruptible industrial loads will convert to firm loads due to changing economic conditions and the increased number of curtailments expected under deregulation. This shift will have the effect of increasing the load which is considered for purposes of reliability assessment and will substantially reduce

reliability in ERCOT. We estimate that shifting half of the interruptible load in ERCOT to firm load would reduce reliability by a factor of about 3.

- The tensions between economics and reliability under deregulation may result in the enforcing of more restrictive limits on transmission loading during "minor" emergencies in attempts to avoid large-scale system collapses. That is, ATC limits may be applied during "minor" emergencies as well as during the scheduling of units and planned transfers. If this is done, reliability as measured by LOLE is likely to degrade by a factor of more than 6.
- ERCOT presently operates in a no-loss sharing mode of cooperation between areas during emergencies. In the past it may have been that some pools, if not ERCOT, operated in all a fully cooperative way to minimize pool load loss even at the expense of shedding some area loads. This loss sharing mode of cooperation during emergencies can result in reliability improvement at the pool level by a factor of about 6. Area reliabilities may improve or worsen under a policy of loss sharing.