IMPACTS OF DEREGULATION ON THE RELIABILITY OF A MULTI-AREA POWER POOL

A. D. Patton and C. Singh
Electrical Engineering Department
Texas A&M University, College Station, TX, USA 77843

D. G. Robinson
Sandia National Laboratories
Albuquerque, NM, USA 87185

Email: patton@ee.tamu.edu, singh@ee.tamu.edu, drobin@sandia.gov

ABSTRACT

The paper describes an investigation of the impacts of deregulation on the reliability, in terms of capacity adequacy, of a large multi-area power pool. The study was conducted using a version of a Monte Carlo simulation-based bulk power system reliability model called NARP. The study examined expected changes in operating policies and other changes expected under deregulation and concludes that reliability is likely to be significantly degraded at least until the transmission network can be strengthened.

Key words: Reliability, Bulk Systems, Deregulation

INTRODUCTION

Electric energy consumers experience two important attributes of electric utility service: cost of energy and service quality including service reliability. Much of the focus of investigations into electric power deregulation has been on the cost of delivered energy, but clearly service quality and reliability are also important and valuable to consumers and will be impacted by deregulation. Accordingly, it is important to understand, quantitatively, the likely impacts of deregulation on reliability so that appropriate steps can be taken to assure the desired level of system reliability performance. In this paper we examine, quantitatively, the reliability implications, in terms of capacity adequacy, of deregulation in a large multi-area power pool in the USA.

The deregulation-related factors which may influence system reliability are many and may include:

1. Reduced generating capacity reserves, at least in the near term, due to market and regulatory uncertainties;
2. Increased reliance on a single fuel, gas;
3. Increased transmission network loading, and resulting congestion, brought about by increasing price competition with associated changes in unit commitment priorities and the resulting increased inter-area transfers of power;
4. Reduced readiness of generating units not expected to be utilized in the course of unit commitment;
5. Changes in policy as regards allowable inter-area power transfers, both for purposes of scheduling and unit commitment and for emergencies;
6. Shifts in some industrial loads from interruptible loads to firm loads as utilities increasingly exercise rights to curtail interruptible loads;
7. Changes in policies of inter-utility cooperation during emergencies as utilities increasingly become competitors;
8. Reduced coordination in the planning of the generation and transmission resources of the bulk power system;
9. Reliance on a new and immature system operations control structure.

In this study we have examined the impacts of factors (3) through (7) which seem to be of importance and general relevance.

The study has been conducted using a version of the NARP model, a Monte Carlo simulation-based model for the quantitative assessment of reliability in a multi-area power system. NARP considers both the random forced outages of generating units and transmission lines as well as deterministic rules governing the commitment of generating units, the scheduling of inter-area transfers, and cooperation during emergencies. Thus, the NARP model is capable of reflecting

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

the deregulation-related factors of interest. The features of the NARP model are described in the section to follow.

NARP SYSTEM RELIABILITY MODEL

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 system operation from which the desired reliability performance indexes can be obtained.

Generating unit forced outages are modeled considering either two or three-state unit models with each state characterized by a capacity and a probability. Generating unit planned outages are modeled deterministically with one or two planned outages per year for each unit. The time to start and load each unit is modeled as a function of the time since the unit was last operated.

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. Thus, the model does not directly model the effects of transmission limitations within an area. Also, physical transmission lines between areas are not explicitly modeled but are reflected in the equivalent transmission links between areas. Thus, a first step in 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 admittance of the equivalent links. The NARP model is designed to model transmission network capacities reflecting both available transmission transfer capabilities (ATC) and total transfer capabilities (TTC). The ATC model assumes first contingency conditions while the TTC model assumes all facilities 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 considered.

Loads can be specified for each area as an 8760-hour or daily peak load cycle for both firm and interruptible loads. The study reported here was conducted on the basis of a daily peak load model. Load forecast uncertainty can be modeled but was not considered in this study.

Firm contracts for power interchanges between pairs of areas are modeled as firm load obligations and create transmission flows. Also modeled are entitlements to percentages of the available capacities of specific out-of-area generating units which create transmission flows depending on the statuses of the generating units in question.

The operating reserve requirement for unit commitment purposes is modeled as a specified MW amount. A specified percentage of the operating reserve can be satisfied by interruptible load and the remainder must be satisfied by the commitment of generation resources.

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

1. 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 limitations imposed by transmission constraints. 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 used in the past for reliability studies for capacity planning purposes.
2. The second set of commitment policies consider the commitment of generating units daily to satisfy load demand plus operating reserve requirements. The units assumed available to serve if needed are the units committed that day plus units which can be started and loaded within about four hours. Three different unit commitment scenarios are considered.

a) Generating units are committed from a pool-wide unit commitment priority list to satisfy pool daily peak load plus operating reserve requirements, 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.
b) Generating units are commited from company or area-specific unit commitment priority lists to satisfy area daily peak loads plus the specified operating reserve requirement of the area while considering firm contracts between areas and entitlements to the capacities of out-of-area generating units. The unit commitment schedule is checked and adjusted as necessary to satisfy the constraints of available transmission transfer capabilities (ATC). This scenario is intended to simulate regulated operation with limited price competition.
c) 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 ATC. This scenario is intended to simulate conditions expected to prevail under deregulation, namely price competition with constraints on interchanges to maintain reliability.

The NARP model is capable of modeling two different policies of cooperation among system areas in the event of capacity shortages. These are called "loss sharing" and "no-loss sharing". 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. This is the policy currently followed in the power pool studied and is expected to be the general policy under deregulation. 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. This policy, which may have been the policy in some pools before deregulation, tends to improve reliability performance at the pool level since this policy permits greater flexibility in the use of resources to maximize flows into areas experiencing shortages. Under either policy 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.

In the present study the reliability index computed for each area and for the interconnected system as a whole is LOLE, the expected number of daily peak load loss events per year. This index is, of course, a measure of steady-state capacity adequacy only. The computed index is separated into two components: "generation constrained" and "transmission constrained" as an aid to analysis. The "generation constrained" component reflects those load loss events due to lack of available generating capacity and defined as loss events for which the available generating capacity within the interconnected system is less than the interconnected system load. Similarly, the "transmission constrained" component reflects those load loss events due to lack of available transmission transfer capability and defined as loss events for which available generating capacity within the interconnected system is greater than the interconnected system load.

THE STUDY SYSTEM

The system studied has been modeled as a ten-area interconnected system with the ten areas representing the major load and generation concentrations of the system. The total installed generation capacities and annual peak firm and interruptible loads for each area and for the system as a whole are shown in Table I. The system generation fleet consists of four nuclear units, 27 coal or lignite units, 190 gas units, 51 combustion turbine units, 20 hydro units, 33 co-generation units and two equivalent units representing the aggregate of a number of diesel units and ties to another power pool. The pool-wide and area-specific unit commitment priority lists place the nuclear and co-generation units first followed by the coal and lignite units, the gas units, and then the combustion turbine and other units. The areas of the study system are not homogeneous in terms of load, generating capacity, capacity reserve margin or mix of generating unit types.

The time to start and load a generating unit is, in general, a function of the time since the unit was last operated. The following rules were used in the study.

- Nuclear units- committed every day

Table I
Generating Capacities and Loads

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

- Coal and lignite units- unavailable on a day unless committed that day (these units generally committed every 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 tie equivalents- available any day whether committed that day or not
- Cogeneration units- regarded as base loaded and committed every day

The transmission network equivalents used in the study were derived from the full a-c load flow model of the system. The derived ATC and TTC models are shown in Table II where the ATC values are shown over the TTC values. Note that the ATC and TTC transfer capabilities between areas of the system are not homogeneous indicating the non-uniform nature of the transmission network of the study system.

For the purpose 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

Table II
ATC and TTC of Transmission Network, MW

	To Area									
From Area	1	2	3	4	5	6	7	8	9	10
1	X	-	305 415	-	-	186 219	239 326	-	-	0 0
2	-	X	65 567	-	-	-	-	-	-	0 145
3	303 1604	1234 2215	X	0 0	59 282	0 260	-	80 1151	-	110 227
4	-	-	160 193	X	-	0 151	-	585 1097	-	743 1052
5	-	-	1 61	-	X	64 128	-	493 1017	0 0	-
6	67 329	-	188 391	277 468	15 151	X	665 978	-	-	55 351
7	327 726	-	-	-	-	797 944	X	-	-	0 272
8	-	-	434 1565	1422 3704	213 745	-	-	X	55 72	716 2126
9	-	-	-	-	496 589	-	-	366 463	X	-
10	818 1608	327 458	54 208	34 718	-	392 790	582 817	16 1071	-	X

generating units. However, 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 generating units, both utility-owned units and co-generation units, exist in the study system. These entitlements create unit-dependent area interchanges. Firm contract interchanges also exist between areas of the system. The sum of unit-dependent and firm contract interchanges between areas of the study system is summarized in Table III.

transmission constraints- the expected practice under deregulation. These cases also assume:

- Reliability indexes are calculated considering firm loads only. That is, it is assumed that the shedding of interruptible loads do not constitute load loss events for reliability purposes. This is the usual approach to reliability evaluation in bulk power systems.
- The system operates in a no-loss sharing mode as regards cooperation during capacity shortage emergencies. This is the present policy of the study system.
- Transmission network flow limitations for purposes of unit commitment and scheduling planned transfers between areas are based on

Table III
Unit-Dependent and Firm Contract Interchanges, MW

To Area

From Area	1	2	3	4	5	6	7	8	9	10
1	X	0	0	0	0	0	0	0	0	0
2	0	X	6	0	0	0	0	0	0	0
3	0	623	X	0	28	29	0	0	0	0
4	0	0	0	X	27.5	0	0	42.5	0	0
5	0	0	0	0	X	14.8	109.7	0	0	0
6	0	0	3	0	0	X	0	43	0	0
7	0	0	0	0	0	0	X	0	0	0
8	0	0	0	15	0	0	0	X	0	1740
9	0	0	0	0	0	0	0	0	X	0
10	700	400	75	88	0	207.5	452.5	410	0	X

The operating reserve requirement in the study system is 2300 MW. Up to 25% of this reserve requirement, or 575 MW, can be satisfied by interruptible load. Thus, for the study 1725 MW of the reserve requirement is met by the commitment of generating capacity and the remaining 575 MW is met by interruptible load.

STUDY CASES AND RESULTS

The first set of cases consider the four different modes of unit commitment previously described: classical planning assumption, commitment on area basis representative of current practice, commitment on pool basis without recognition of transmission constraints, and commitment on modified pool basis with recognition of

available transfer capabilities (ATC), but flows during emergencies are limited only by total transfer capabilities (TTC). That is, no transmission capacity is held in reserve during emergencies. This is the present policy of the study system.

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

- Considering reliability at the pool level, reliability is seen to decrease under deregulation (LOLE increases). The amount of LOLE increase depends on the models thought to be most representative. If regulated practice is modeled most accurately by the "area commitment-basis" model and deregu-

Table IV
Area and Pool Reliability, LOLE

Area	Classical	Area-Based	Modified Pool-Based	Pool-Based
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%

lated practice is modeled most accurately by the "modified pool commitment-basis" model, then reliability is seen to be degraded by about a factor of 2.6 if the study system is deregulated. The factor of reliability degradation may be larger, up to about 12, if the classical modeling assumptions are more accurate for regulated operation and if constraints on transmission usage are not enforced under deregulation.

- The change in area reliability under deregulation is not uniform. Some areas are seen to benefit while others suffer reliability degradation under deregulation. This follows from the non-homogeneous character of the pool.
- Table IV also shows the percentage of load loss events at the pool level which are caused by transmission capacity shortages. Note in the study system that the large majority of load loss events are transmission-caused. However, discounting the classical model as probably inaccurate, the percentage of transmission-caused load loss events is seen to increase under deregulation. Clearly, reliability in the study system would greatly benefit from an increase in transmission network capacity.

An obvious trend in the study system and elsewhere is the increasing number of curtailments of interruptible loads as authorized under their tariffs. In the past interruptible loads were rarely actually curtailed. Therefore, in the future under deregulation it seems likely that many interruptible loads will become firm loads. If this occurs, the loads used for reliability assessment will increase. To study this effect we have considered two scenarios: 100% of interruptible load converted to firm load and 50% of interruptible load converted to firm load. Under the 100% conversion scenario, LOLE for the "modified pool commitment-basis" model, the model believed to best simulate conditions under deregulation, rises to 38.71 with 76.8% of the load loss events caused by transmission shortages. Similarly, under the 50% conversion scenario, LOLE rises to 16.81 with 90.1% of the load loss events caused by transmission shortages. Thus, if 100% of interruptible loads were to convert to firm loads, reliability as calculated considering firm load loss events only would degrade by a factor of about 18.2 under deregulation. Similarly, 50% load conversion would result in reliability degradation under deregulation by about a factor of 7.9.

The results presented so far assume that all inter-area transfers are scheduled under conservative ATC transmission limits, but that all transmission resources would be used in emergencies. This is the current policy of the study system. Some systems may, however, utilize more conservative transmission transfer limits even under emergencies short of total system jeopardy in efforts to avoid total system collapse. We have studied this situation by assuming the use of ATC transfer limits both for unit commitment and for emergencies. Here, using the "modified pool commitment-basis" model, reliability in terms of LOLE is degraded by a factor of about 32 as compared to results obtained assuming use of TTC limits during emergencies. Thus, the possible trend to use of more conservative transmission limits for "minor emergencies" under deregulation is likely to greatly increase LOLE, the expected number of days per year on which at least some load loss is experienced.

The study system presently has a policy of cooperation during emergencies which amounts to "no-loss sharing" and the preceding study cases have all assumed this mode of cooperation. However, in the past we believe many systems have operated under a policy amounting to "loss sharing" but that the trend under deregulation may be to a policy of no-loss sharing. Therefore, we have studied the effect of this policy using the "modified pool commitment-basis" model with other assumptions the same as in the studies of Table IV. We find that a policy of loss sharing results in LOLE at the pool level which is about 15% of that for a policy of no-loss sharing. Evidently, any trend under deregulation to a policy of reduced cooperation during emergencies will substantially reduce reliability at the pool level.

CONCLUSIONS

Based on the study, we conclude that the reliability (adequacy) of bulk power systems, as measured at the system or pool level, is likely to be substantially degraded under deregulation at least until transmission networks are strengthened to accommodate the new mode of operation. It is also clear from the study that in a non-homogenous pool area reliability effects may not be consistent or uniform and may only roughly track pool reliability effects.

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.

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 large factor.

The study system presently operates in a no-loss-sharing mode of cooperation between areas during emergencies. In the past it may have been that some pools operated in 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 substantial reliability improvement at the pool level. Area reliabilities may improve or worsen under a policy of loss-sharing.

ACKNOWLEDGEMENT

The study was conducted under Sandia National Laboratories contract BC-4158.