AN APPRAISAL OF NEPA'S GENERATION ADEQUACY TO YEAR 2000

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Abstract
A comprehensive framework for an assessment of NEPA's generation adequacy is presented. Generation adequacy is the ability of a generation to supply its load taking into account the load fluctuations and random events that affect generation capacity. To assess this ability, depending on the assessment horizon, present and future load demands are prerequisites. Load forecast for 1989 through 2000 is presented. Reliability/adequacy indices which provide the means for quantifying system's generation adequacy are considered. Generation adequacy assessment techniques are discussed and the loss of load method adopted. This method is demonstrated by applying it to the NEPA system and the generation adequacy assessed. Finally, a graphic representation of NEPA's adequacy is presented.

1. Introduction

Energy system consists of an integrated set of technical and economic activities operating within a complex societal framework. The energy sector of an economy has a strong influence on the overall economic development and a lasting effect on national and international decisions. It is a problem of growing complexity and therefore needs both short-term and long-term policies for solution.

Electricity, among other forms of energy; solar, nuclear, e.t.c., is the only developed form of energy in Nigeria (harnessing of other forms of energy is still on the drawing board). The generation of this vital form of energy in Nigeria is the statutory responsibility of the National Electric Power Authority (NEPA). The close tracking of the system load by the generation at all times is a basic requirement in the operation of any electric power utility. This problem is further accentuated by the fact that electricity cannot be stored and a lead-time of about six to ten years [1] is required from project approval to commissioning. Moreover, any error in tracking the system load by the system generation results in increased operating costs. In the Year 1985, for the predominantly thermal British power system; it was estimated that a 1 percent increase in the forecasting error was associated with an increase in operating costs of $10 million per year [1]. A periodic assessment of the performance of NEPA presented in this paper which will lead to a prognostic p1annig of the electricity industry should therefore be a useful exercised.

In recent times generation-adequacy assessment technique has received a widespread attention (3-7). The available techniques are the loss of load probability/expectation (LOLP/E) method, and the frequency and duration (F&D) method [5]. These methods provide numerical indices which reflect the static adequacy of the .installed generation capacity.

The LOLP/E method is widely used in electric power industry due to its flexibility and simplicity of application [5]. Irrespective of the method the overall basic approach is as follows:

i. Develop a suitable load model from the parameters of the individual generating units.
ii. Develop a suitable load model from the given data over the period of study.
iii. Combine the capacity model with the load model to obtain a probabilistic model or system capacity adequacy.

In NEPA today, due to inconsistency of data, a method that discards units whose records are Dot available for upwards of eight months is in use [10]. This method results in inaccurate estimation of the generation adequacy. In this paper, a new strategy that takes these units (now assumed to be peaking units) into consideration in the generation model computation is presented.

2. The Concept of Adequacy

In electric power system studies, terms like reliability, adequacy, dependability and security are frequently used interchangeably without any loss in generality, since all are concerned with the measure of the quality and constancy of service. In recent times, however, the state of the art has been to distinguish among these terms. To this end, Bhavaraju at al [11] defined system adequacy as the ability of a systems to supply its load taking into account scheduled and unscheduled outages of the system components.

An outage describes the state of a component when it is not available to perform is intended function due to some events associated with that component.

Some of the common causes of generating unit outages in NEPA may be listed as follows:

i. Insufficient inflow or low level of water due to drought or late rains to drive the turbines in hydro power stations.
ii. Inadequate supply of fuel in thermal power stations.
iii. Lack of spare parts for depreciating equipment.
iv. Shortage of qualified engineers to render required and timely maintenance service to equipment.

2.1 Generating System Adequacy Indices

In generating system adequacy studies, mostly probabilistic indices (criteria) are employed. Deterministic indices in terms of generating reserve capacity are now considered obsolete. The basic indices will now be briefly reviewed:

i. LOLE: This describes the probability of the system load exceeding the available generating capacity under the assumption that the peak load of each day lasts all day. This measure is expressed in units of day/year.
ii. LOLP: This describes the expected number of days in a year when loss of load occur. This measure does not imply that the failure lasts all day.
iii. The frequency of system failure which is the mean number of occurrences per unit time of system failure.
iv. The average duration of failure.

In essence, the only difference between the first two indices is that in LOLP calculation, daily peak load data is used whereas in LOLE calculation, hourly peak load data is used. The two indices are practically the same and are not consistently defined in various countries. In this paper, LOLP and LOLE are used interchangeably to mean, the same.

2.2 The Forecaster

As noted previously, future load demand is necessary in power systems generation adequacy study. For coarse forecasting as, is applicable in this case, the use of a simple time fitting function which presupposes that weather, socio-demographic and economic conditions do not appear explicitly in the forecast is a reasonable approach [4]. In practice, suitable fitting functions for peak load forecasting include linear, quadratic, logarithmic and exponential functions. In this paper, linear model which gives the best fit for the NEPA data under study (annual maximum load data for 1973 through 1988) is used with forecast result being shown in Table.

3. Assessment of Generation Adequacy

In generation adequacy assessment, the available generation is combined with the load demand. Available techniques require two mathematical models: one for the state of generation (generation capacity outage table (COT)), and the other for the load variations (load duration curve (LDC)). The reliability/adequacy indices which are then used in adequacy studies. In this section, the two mathematical models, namely, the COT and the LDC will be discussed

3.1 Generation COT:

This is a probability table listing the amount of generation on forced outage versus the probability of that operating state. Forced outage rates (FOR's) or unavailability of units are required in COT construction. FOR may be defined mathematically as

$$FOR = \frac{FOH}{FOH+ISH}$$

where FOH is the forced outage hours and ISH is the in service hours. For units with partial outages (derated operations,) the FOH is increased by an appropriate amount of time called the equivalent forced outage hours (EFOH); obtained by multiplying the actual partial outage hours by the corresponding fractional capacity reduction and the product summed up. The ISH now includes the partial outage time as well. The resulting index is the equivalent forced outage rate (EFOR), which may be expressed as

$$EFOR = \frac{FOH+ EFOH}{FOH+ ISH}$$

By the introduction & the index, EFOR, the model for a generating unit with partial outages is reduced, with a good approximation, to the two-state model for a unit with full outage only.

Generally, peaking units have relatively low in-service time. As a consequence, the FOR calculated for these units using the conventional definition is very high and unrealistic. This is because for a unit not constantly in demand, FOH erroneously include periods, when the unit is not needed. A more appropriate model will be obtained by separating the FOH into demand and non-demand portions. The result may be expressed as

$$FOR = \frac{FOH_{demand}}{FOH_{demand} + ISH}$$

This model is also application to lead units.

3.2 FOR Estimation

Some evidence exist that units FOR's increase with increasing size [7]. The generation FOR data published by Edison Electric Institute (EEl) indicates an increase of FOR for large units. A subsequent statistical analysis of data by the National Electric Reliability Council, U.S.A., shows that unit FOR can be approximated by the following relation

$$FOR(S) = 0.02 + 0.23(1 - E^{0.002s})$$

where s is the unit size in MW. However, FOR'S for very large units evaluated by the above expression may be too high. Consequently, the application of this empirical formula is limited to small, medium and large units. In some applications, a constant FOR may be assumed for certain units when data is not available.

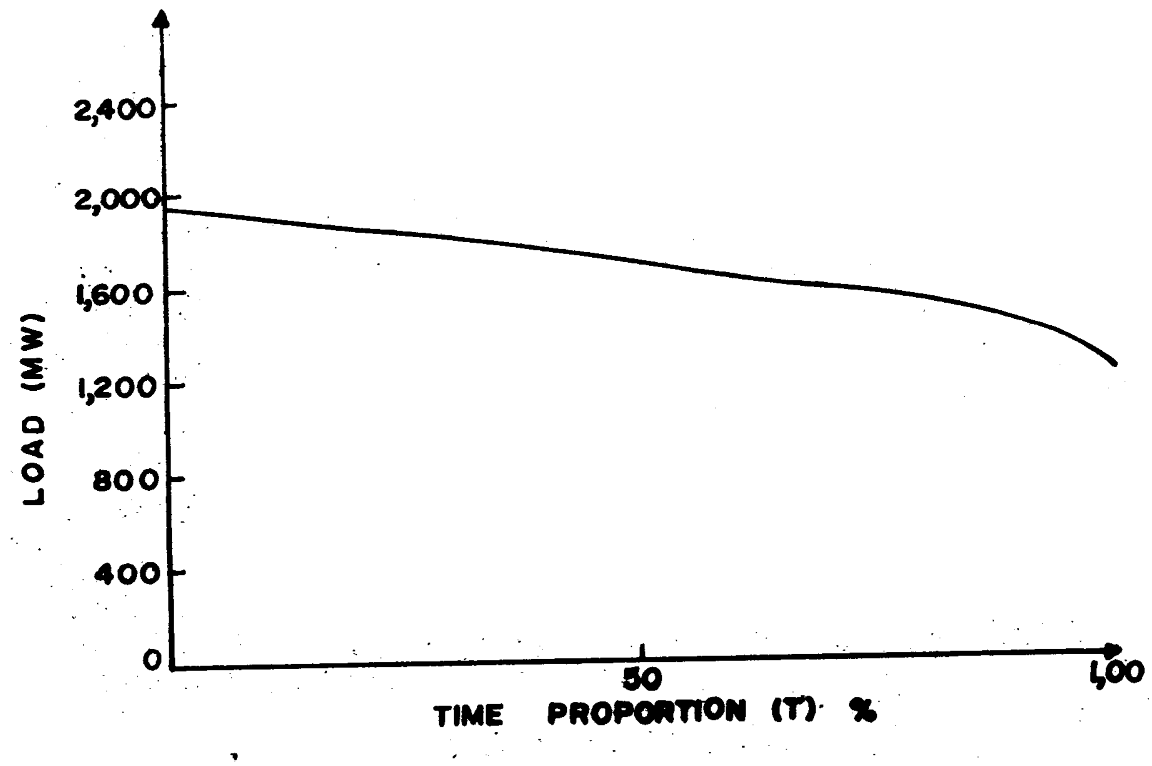

Figure 1:1988 Daily peak Load – Duration curve.

TABLE 1: NEPA UNITS CAPACITY AND FORCED OUTAGE RATES (FORs)

Station	Unit	Installed Capacity (mw)	FOR	Station	Unit	Installed Capacity (mw)	FOR
AFAM	1	10	*	JEBBA	1	90	.01
AFAM	2	10	*	JEBBA	2	90	*
AFAM	3	17.5	*	JEBBA	3	90	.01
AFAM	4	17.5	*	JEBBA	4	90	.012
AFAM	5	25	.01	JEBBA	5	90	.01
AFAM	6	25	.01	JEBBA	6	90	*
AFAM	7	25	.02	KAINJI	1	120	.003
AFAM	8	25	.012	KAINJI	2	120	*
AFAM	9	25	*	KAINJI	3	80	*
AFAM	10	25	*	KAINJI	4	80	.01
AFAM	11	25	*	KAINJI	5	80	.003
AFAM	12	25	.01	KAINJI	6	80	.004
AFAM	13	70	*	KAINJI	7	100	.001
AFAM	14	70	.01	SAPELE (STEAM)	1	116	*
AFAM	15	70	.01	SAPELE	2	116	*
AFAM	16	70	.01	SAPELE	3	116	.02
AFAM	17	70	.01	SAPELE (STEAM)	4	116	.02
AFAM	18	70	*	SAPELE (STEAM)	5	116	.014
DELTA	1	36	*	SAPELE (STEAM)	6	116	*
DELTA	2	36	*	SAPELE (GAS)	1	70	*
DELTA	3	20	.01	SAPELE (GAS)	2	70	.01
DELTA	4	20	.02	SAPELE (GAS)	3	70	.013
DELTA	5	20	.01	SAPELE (GAS)	4	70	*
DELTA	6	20	*				
DELTA	7	20	*				
DELTA	8	20	.02				
DELTA	9	20	.03				
DELTA	10	20	.01				
DELTA	11	20	.01				
DELTA	12	20	.011				
DELTA	13	20	.02				
DELTA	14	20	.01				
EGBIN	1	220	.01				
EGBIN	2	220	.01				
EGBIN	3	220	.01				
EGBIN	4	220	*				
EGBIN	5	220	*				
EGBIN	6	220	*				
IJORA	1	20	*				
IJORA	2	20	*				
IJORA	3	20	.011				

TABLE 2: NEPA ORDERED GENERATION LIST.

Unit	CAPACITY (MW)	FOR	UNIT	CAPACITY (MW)	FOR
1.	220	.10	34.	70	.02
2.	220	.10	35.	70	.02
3.	220	.10	36.	70	.02
4.	220	.02	37.	36	.02
5.	220	.02	38.	36	.02
6.	220	.02	39.	25	.02
7.	120	.003	40.	25	.012
8.	120	.02	41.	25	.01
9.	116	.014	42.	25	.02
10.	116	.02	43.	25	.02
11.	116	.02	44.	25	.02
12.	116	.02	45.	25	.01
13.	116	.02	46.	25	.01
14.	116	.02	47.	20	.011
15.	100	.02	48.	20	.01
16.	90	.011	49.	20	.01
17.	90	.01	50.	20	.02
18.	90	.012	51.	20	.01
19.	90	.01	52.	20	.02
20.	90	.01	53.	20	.03
21.	90	.02	54.	20	.01
22.	90	.02	55.	20	.01
23.	80	.003	56.	20	.011
24	80	.004	57.	20	.02
25.	80	.001	58.	20	.02
26.	80	.02	59.	20	.02
27.	70	.01	60.	20	.02
28.	70	.013	61.	20	.02
29.	70	.01	62.	17.5	.02
30.	70	.01	63.	17.5	.02
31.	70	.01	64.	10	.02
32.	70	01	65.	10	.02
33	70	.02			

3.3 computation of Generation COT

The complexity involved in the computation of COT has led to the use of the building algorithm wherein the generation list is read in one unit at a time and the COT is constructed as the units are read. The data from NEPA shown in Table 1 comprises the installed unit capacities and their respective FORs. In order to minimize the error associated with the COT construction, Table 1 is rearranged with unit capacities in descending order of magnitude as shown in Table 2. In both Tables 1 and 2, units with FORs marked asterisks have no available FOR at NEPA. For such units a constant FOR of 0.02 is assumed. As would be seen from the results obtained, the assumption has been justified.

3.4. Load Duration Curve (LDC)

In this sub – section, the LDC for the year 1988 is presented. The available data are the daily speak loads for 263 days of the years 1988 under review

Table 3: 1988 Daily Peak Loads (MW)

1952	1950	1945	1928	1922	1917
1909	1907	1907	1906	1902	1899
1888	1888	1882	1880	1878	1877
1877	1868	1866	1865	1864	1863
1862	1861	1855	1855	1849	1849
1843	1842	1842	1840	1839	1836
1832	1831	1828	1828	1828	1828
1824	1821	1817	1815	1813	1811
1811	1809	1808	1804	1804	1803
1802	1799	1797	1796	1796	1796
1794	1786	1785	1785	1784	1782
1781	1779	1778	1778	1777	1776
1773	1773	1773	1772	1772	1772
1768	1768	1765	1763	1763	1755
1753	1750	1747	1747	1744	1741
1741	1740	1740	1736	1773	1732
1730	1729	1727	1726	1725	1724
1720	1791	1719	1714	1714	1711
1710	1708	1708	1706	1704	1703
1700	1697	1695	1693	1689	1688
1684	1683	1678	1675	1673	1669
1665	1660	1656	1655	1653	1652
1651	1651	1649	1641	1641	1635
1651	1651	1649	1641	1641	1635
1634	1634	1632	1629	1628	1626
1624	1621	1619	1617	1616	1615
1615	1612	1607	1604	1603	1601
1600	1595	1594	1591	1585	1585
1584	1582	1582	1580	1579	1575
1575	1574	1573	1570	1566	1566
1565	1565	1564	1564	1561	1560
1559	1555	1553	1551	1548	1543
1538	1532	1529	1528	1526	1525
1518	1518	1510	1509	1508	1505
1563	1503	1502	1499	1499	1492
1491	1491	1488	1486	1483	1475
1475	1472	1471	1467	1466	1465
1461	1455	1454	1450	1449	1449
1448	1441	1440	1440	1438	1437
1434	1433	1430	1430	1422	1411
1405	1404	1395	1393	1388	1387
1386	1378	1377	1377	1376	1375
1375	1362	1357	1354	1351	1345
1344	1327	1321	1320	1309	1277
1251	1246	1244	1240	1234	

Table 4: 1988 Daily Peak Loads Distribution

Range (MW)	Frequency of Occurrence	Percentage
1952 – 1907	9	4
1906 – 1861	17	7
1860 – 1815	20	8
1814 – 1769	32	12
1768 – 1722	24	9
1721 – 1674	22	8
1673 – 1628	19	7
1627 – 1582	22	8
1581 – 1536	22	8
1535 – 1490	19	7
1489 – 1444	17	7
1443 – 1398	13	5
1397 – 1352	14	5
1351 – 1306	7	3
1305 – 1260	1	0
1259 – 1214	5	2

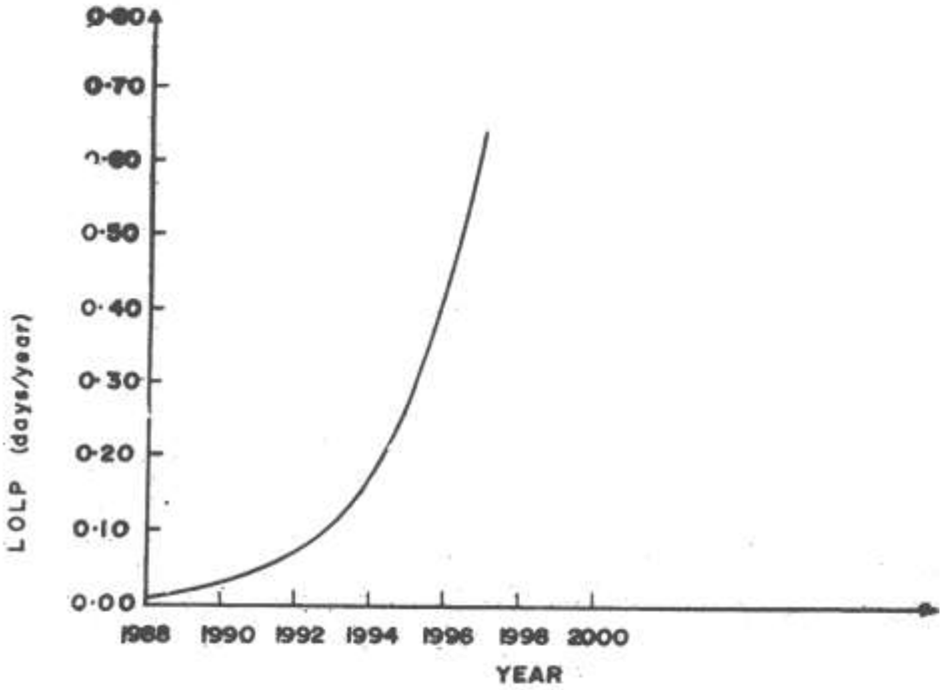

Figure 2: LOLP for the years 1988 througn 2,000.

and arranged in descending order of magnitude as shown in Table 3. The frequency of occurrence of the daily peaks within a chosen range of 45MW is computed and expressed in their respective percentage as shown in Table 4. This table is used to construct the LDC shown in figure 1.

The load model for any subsequent year is obtained by adding the difference between the year's forecast peak load and the reference year's peak load to load model of the reference year.

4. Results

The LOLP/E indices for the year 1988 through 2000 were calculated using the COT and the LDC. The results obtained are graphically illustrated in figure 2. The results indicate that NEPA's generation was adequate for the years 1988 through 1992, but inadequate for 1993 and subsequent years based on the accepted standard of 0.1 day per year.

5. Conclusions

This paper has presented a new comprehensive generation adequacy appraisal strategy for the National Electric Power Authority (NEPA). The loss of load method presented in this paper for calculating adequacy indices is recommended for NEPA because of the nature of the data available at NEPA. As noted previously, in NEPA today, generating units that do not have their records available for upwards of 8 months are discarded in COT construction. This is not a good approximation and has resulted in inaccurate estimation of NEPA's generation adequacy. The method presented in this paper in which every unit is taken into consideration should be adopted.

The generation adequacy graphically illustrated in figure 2 shows that NEPA's generation was adequate for 1988 through 1992, but inadequate as from 1993 based on the accepted standard. This suggest that optimum unit size should be added in 1993 to redress the situation. Finally, the results indicate that the frequent "blackouts" experienced currently in the country are due to transmission and distribution inadequacies;

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