Probabilistic Electrical Power Generation Modeling Using Decimal to Binary Conversion

Ahmed S. Al-Abdulwahab

***Abstract*—**Generation system reliability assessment is an important task which can be performed using deterministic or probabilistic techniques. The probabilistic approaches have significant advantages over the deterministic methods. However, more complicated modeling is required by the probabilistic approaches. Power generation model is a basic requirement for this assessment. One form of the generation models is the well known capacity outage probability table (COPT). Different analytical techniques have been used to construct the COPT. These approaches require considerable mathematical modeling of the generating units. The unit's models are combined to build the COPT which will add more burdens on the process of creating the COPT. Decimal to Binary Conversion (DBC) technique is widely and commonly applied in electronic systems and computing This paper proposes a novel utilization of the DBC to create the COPT without engaging in analytical modeling or time consuming simulations. The simple binary representation , "0 " and "1 " is used to model the states o f generating units. The proposed technique is proven to be an effective approach to build the generation model.

***Keywords*—**Decimal to Binary, generation, reliability.

I. INTRODUCTION

GENERATING adequacy assessment is an important aspect of power system planning. In order to maintain a desired level of reliability, the system must have a capacity reserve in excess of the actual load demand. Many techniques have been developed to determine the required level of capacity reserve in a system. These techniques can be divided into two types, probabilistic and deterministic [1]-[4]. A number of Canadian surveys have been conducted and it was concluded from these surveys that Canadian utility practice has moved over time from deterministic approaches to probabilistic techniques [5].

Two models are required to conduct probabilistic adequacy assessment of the system, the load model and the generation model. The most commonly used load models are the daily peak load variation curve (DPLVC), and the load duration curve (LDC). These two models are fairly straight forward to build. The generation model is usually presented in the form of a capacity outage probability table (COPT) which includes the available or unavailable capacity levels and their corresponding probabilities. The COPT has been created using different techniques [6]-[9]. These approaches can be categorized into two main categories analytical methods and simulation techniques. Analytical approaches require mathematical modeling for the generating units. The unit's models are then combined to generate the system states which will add more burdens on the process of creating the COPT. Monte Carlo Simulation (MCS) does not require extensive mathematical modeling, however, a large number of simulation need to be considered to reach an acceptable confident level. Moreover, MCS is a random process in which system states can be repeated many times unnecessarily. The Genetic Algorithm (GA) search technique used to generate the COPT. It starts with a random population of system states. Then, it goes through a number of iterations and reproduction operations. The accuracy of the resulting COPT can be greatly affected by the values of the GA parameters. The proposed technique utilizes the DBC to create the COPT. DBC does not require complicated analytical representation, time consuming simulation nor reproduction process.

DBC technique is widely and commonly applied in electronic systems and computing. This paper presents a novel application of the DBC in power system reliability analysis. It is utilized to create the COPT. The concepts presented are demonstrated by application to a small test system and to the RBTS.

Ahmed S. Al-Abdulwahab is with the Electrical and Computer Engineering Department, College of Engineering, King Abdulaziz University, P.O.Box 80204, Jeddah 21589, Saudi Arabia (aabdulwhab@kau.edu.sa).

II. DECIMAL TO BINARY CONVERSION METHOD

DBC is used to create the COPT. A single column array is created that contains decimal numbers. These numbers are converted to their binary representations and stored in a binary states array. This array is used to calculate the states probabilities and capacities. The proposed application of the DBC to build the COPT is summarized in the following steps:

1- Define the number of possible outcomes (states) which is 2^N where:
N: Number of generating units

2- Create an array that contains the decimal numbers 0, 1, 2, 3,….., (2^N-1). This array is designated as the decimal states array with the size of 2^N*1.

3- Convert the decimal states array to the corresponding binary numbers. This operation results in a new binary array designated as the binary states array. Each row represents one system state. The number of binary digits in each row equals to the number of units in the system. Each digit can be (0) or (1) which represent the status of the corresponding unit. The (1) means that the unit is in-service and the (0) means that the unit is out of service. The general binary states array is shown below.

$$Binary\ \ States\ \ Array = \begin{bmatrix} State_{11} & State_{12} & . & . & State_{1N} \\ State_{21} & State_{22} & . & . & State_{2N} \\ & . & & & \\ & & . & & \\ & & & . & \\ State_{2^N 1} & State_{2^N 2} & . & . & State_{2^N N} \end{bmatrix}$$

4- Equation 1 is used to calculate the state capacity,

$$State\ Capacity_i\ (MW) = \sum_{j=1}^{N} State_{ij} * Cap_j \qquad (1)$$

Where,
$State_{ij}$: the state of the jth unit in the ith system state.
Cap_j: the capacity of the jth unit.

Usually, in the COPT, the capacity on outage for each state (State Cap Out_i) is used which can be calculated using (2),

$$State\ Cap\ Out_i\ (MW) = TIC - State\ Capacity_i \qquad (2)$$

Where,
TIC: The Total Installed Capacity

5- The state individual probability is calculated using (3).

$$State\ \ probability_i = \prod_{j=1}^{N} prob_j \qquad (3)$$

Where,
$prob_j = FOR_j$ if $state_{ij} = 0$
$= 1 - FOR_j$ if $state_{ij} = 1$

6- In some cases, there might be some of the states that have equal capacity levels. These states are replaced by a single state with this capacity level. The probability of this state is the sum of the probabilities of these states.

III. Case Study

The technique described above is illustrated using a small system composed of three generating units. The units data are shown in Table 1.

TABLE I
TEST SYSTEM DATA

	Capacity (MW)	FOR
Unit 1	10	0.02
Unit 2	30	0.04
Unit 3	20	0.10

The decimal states array = $[0 \quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7]'$

Each element of the decimal states array is converted to its binary value as shown below.

$$\text{The binary states array} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Note that each row in the binary states array represents a single system state with three units. The state capacity is calculated using (1). Note that, States 3 and 6 have the same capacity level and therefore, these two states will be combined in a single state later on. Note that only a sample calculation is presented for the first three states.

State Capacity1 = 0 * 10 + 0 * 30 + 0 * 20 = 0 MW
State Capacity2 = 0 * 10 + 0 * 30 + 1 * 20 = 20 MW
State Capacity3 = 0 * 10 + 1 * 30 + 0 * 20 = 30 MW
State Capacity4 = 50 MW
State Capacity5 = 10 MW
State Capacity6 = 30 MW
State Capacity7 = 40 MW
State Capacity8 = 60 MW

The out of service capacities is calculated using (2) by knowing that the TIC is 60 MW.

State Cap Out1 = 60 – 0 = 60 MW
State Cap Out2 = 60 – 20 = 40 MW
State Cap Out3 = 60 – 30 = 30 MW
State Cap Out4 = 10 MW
State Cap Out5 = 50 MW
State Cap Out6 = 30 MW
State Cap Out7 = 20 MW
State Cap Out8 = 0 MW

Equation 3 is used to calculate the state probability.

State probability1 = 0.02 * 0.04 * 0.10 = 0.00008
State probability2 = 0.02 * 0.04 * (1 - 0.10) = 0.00072
State probability3 = 0.02 * (1 – 0.04) * 0.10 = 0.00192
State probability4 = 0.01728
State probability5 = 0.00392
State probability6 = 0.03528
State probability7 = 0.09408
State probability8 = 0.84672

The final COPT is shown in Table 2. As noted above that States 3 and 6 have the same capacity level and therefore, the probabilities of these two states are added together. The system states were rearranged in a descending order based on the capacity in service.

It can be seen from Table 2 that the total state probability is 1.0 which means that all of the system states are included in the table.

TABLE II
THE FINAL COPT FOR THE TEST SYSTEM.

State	Cap. In Service (MW)	Cap. Out of service (MW)	Probabilities
1	60	0	0.84672
2	50	10	0.01728
3	40	20	0.09408
4	30	30	0.03720
5	20	40	0.00072
6	10	50	0.00392
7	0	60	0.00008
Total state probability			1.0

The final COPT shown in Table 2 obtained for the three-units test system was verified and compared with the results obtained for the same system using the GA search technique presented in [8]. This comparison yields identical results.

The developed technique is applied to the RBTS [10]. The RBTS is an educational test system that has 11 generating units, ranged from 5 MW to 40 MW. The total number of states for the RBTS is 2^{11} (2048) states. Table 3 shows a comparison between the DBC technique and the GA search method. The D technique yields the exact table with all states. This result was obtained without going through any iterations or approximation. The GA search technique with a population size of 1000 and generation size of 100 recovered 1267 states out of 2048 with a cumulative probability of 0.99999783 [8].

TABLE III
THE GA SEARCH TECHNIQUE AND THE DBC METHOD APPLIED TO THE RBTS.

	GA search method	DBC method
Cumulative probability	0.99999783	1.0
Number of states	1267	2048

IV. CONCLUSIONS

This paper presented an effective method based on the DBC to create the power generation model. This model is one of the basic requirements for the generation power system reliability evaluation. The proposed approach does not requires complicated modeling nor time consuming simulation to generate the system states. The binary representation , “0 ” and “1 ”, is used to represent the states of the generating units. The proposed technique was validated and tested on the RBTS.

REFERENCES

[1] IEEE Committee Report, “Bibliography on the Application of Probability Methods in Power System Reliability Evaluation,” 1971-1977, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-97, No. 6, 1978, pp. 2235-2242.

[2] R. N. Allan, R. Billinton, and S. H. Lee, 1984. Bibliography on the Application of Probability Methods in Power System Reliability Evaluation, 1977-1982, IEEE Transactions on Power Apparatus and Systems, PAS-103, pp. 275-282, No. 2.

[3] R. N. Allan, R. Billinton, S. M. Shahidehpour, and C. Singh, “Bibliography on the Application of Probability Methods in Power System Reliability Evaluation,” 1982-87, IEEE Transactions on Power Apparatus and Systems, Vol. 3, No. 4, 1988, pp. 1555-1564.

[4] R. Billinton, “Bibliography on the Application of Probability Methods in Power System Reliability Evaluation,” IEEE Transactions on Power Apparatus and Systems, Vol. 91, No. 2, 1972, pp.649-660.

[5] R. Billinton, “Criteria Used by Canadian Utilities in the Planning and Operation of Generating Capacity,” Applied Reliability Assessment in Electric Power Systems, IEEE press, New York, 1991, pp. 186-191.

[6] R. N. Allan, R. Billinton, “Reliability Evaluation of Power Systems,” Plenum Press, New York 1996.

[7] C. Singh, and N. V. Gubbala, “Comparison of unit addition and fast Fourier transform methods for generation system reliability evaluation,” Electrical Power & Energy Systems Vol. 18 No. 4, 1996, pp. 203-205.

[8] A. Al-Abdulwahab, “Probabilistic Electrical Power Generation Modeling Using Genetic Algorithm,” International Journal of Computer Applications 5(5):1–6, August 2010. Published By Foundation of Computer Science.

[9] R. Billinton and A. Abdulwhab, "Short-term generating unit maintenance scheduling in a deregulated power system using a probabilistic approach", IEE, Proc.-Gener. Trans., Vol. 150, No. 4, July 2003, PP. 463-468.

[10] R. Billinton, S. Kumar, K. Chowdhury, K. Chu, K. Debnath, L. Goel, E. Khan, P. Kos, G. Nourbakhsh, and J. Oteng-Adjei, “A Reliability Test System for Educational Purposes – Basic Data,” IEEE Transactions on Power Systems, Vol. 4, No. 3, 1989, pp. 1238-1244.

Ahmed S. Al-Abdulwahab obtained a B.Sc. Degree from King Abdulaziz University and MSc. and PhD degrees in Electrical Engineering from the University of Saskatchewan, Canada. He was the vice dean for development at Jeddah Community College, King Abdulaziz University. He is a faculty member at the electrical and computer engineering department, college of Engineering at the same university. He was a consultant for the Electricity and Co-generation Regulatory Authority in Saudi Arabia. Currently, he is a visiting professor at the University of Saskatchewan, Canada. His research interest includes power system reliability, power system planning, genetic algorithm and maintenance scheduling.