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LOLE Calculation and Capacity Margin Probabilities Neuro-Fuzzy Model Development

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Abstract: Any power system needs a comprehensive study. The reliability of the system is a must, where the appropriate loss term is one of the required terms. In the present study, the Loss of Load Expectation (LOLE) is targeted. In addition, the LOLE is estimated using the advanced Adaptive Neuro-Fuzzy Inference System (ANFIS) method. The LOLE and the Capacity Margin Probabilities (CMP) are calculated. The main target of the present study is to avoid the black-out of the system which is the novelty of the study for the considered power system which helps for a high reliable system also. Furthermore, the satisfaction of the economic development for the countries resulted using the developed model and the demand energy will be reached for different sectors at a required period. The results obtained for any considered country are reducing the capital investment and helping to limit the installed equipment plus the expectation of the load. Finally, the Neuro-Fuzzy is one of the most accurate methods. It is applied in the planning and development of electric power systems.

Keywords: CMP, LOLE, EF, NFuzzy.

1. Introduction

The flexible electricity network is provided by the smart grid which uses the generation distribution and improves both of balancing and control of power flow. In addition, the smart grid enhanced fault protection, includes the micro-generation and energy storage. Also, the smart grid technology enables surveillance infrastructure, and network assets control. Nevertheless, the smart grid should result into supply security and higher energy efficiency. A question raised when the operating costs and investment reduced? This question needs an answer. The answer becomes that the generation design is the target which provides sufficient production units for the future. Furthermore, the generation design will satisfy the load requirements. These requirements will help to reach a specific targeted reliability of the main task, financial and environmental constraints. To reach a specific target, the design method raised production capacity. Raising production capacity is satisfied by a new generation units' addition. This will help to meet the requirements of the full system loading.

The term LOLE is defined in Qamber [1] as one of the power system reliability indices. The term LOLE is called the expected number of days in one year. In other words, the available capacity is not sufficient to serve the daily maximum electric load. Another definition of that and during the observation of the electric load cycle, the expected number of hours are determined when insufficient capacity is available to satisfy the targeted load at any instant. Furthermore, as a definition of the Reserve Margin [1] it is the percentage of any additional installed capacity within a time that the annual peak load is considered. Several examples are discussed and explained in Qamber [1] for the reserve margin probabilities and the loss of load expectation.

The optimal design and energy management of the hybrid systems are discussed and considered by Moghaddam et al [2] in their study. In addition, they [2] applied the intelligent flower pollination algorithm to minimize the total net cost. Two terms were considered in their research, these terms are the loss of energy expected and LOLE.

Qamber and Al-Hamad in their research book [3] evaluation and monitoring the electrical system cost cycle. The evaluation and monitoring are carried out by recording the estimated hours (i.e., Hourly Loss of Load Expectation) or the time when insufficient generation capacity is available to determine the required charge simultaneously.

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It should be known that the LOLE is known as the production capacity reached insufficient maximum daily load. In other words, the daily/annual peak LOLE as a reliability term. Qamber and Al-Hamad in their research book [3] discussed both LOLE and LOLP, where they found that LOLE is used more often than the LOLP.

Čepin [4] in his research includes the LOLE gradually restoring more compact energy sources. In the same way, Čepin analyzes the power nuclear and wind plants and compare between them in different scenarios in terms power reliability. The study of Čepin [4] concerns the basic works. The study consists of twelve power plants, where one of which is nuclear power plant. Soon After, three wind farms replacing the nuclear power plant. This helps the power station capacity reached a total of five times the earlier capacity of the power station.

Qamber in his study [5] treats with two reliability terms called LOLP and LOLE. The LOLP and LOLE as a power system reliability terms assist in the design, operation, and maintenance. Qamber [5] highlights on both terms of the LOLP and LOLE. Both terms are the lost electric loads exceeding the generation capacity of electric power system considering in the study.

In the studies [6, 7], the Value of Loss Load against Average Net hourly Wage ($) are calculated. The calculation is helping in assessing the system reliability. A question raised about the (VOLL) calculation. This question regarding the target of this term (VOLL). The target is to ensure the most effective and efficient provision of resource adequacy and the domestic Value of Loss Load which is calculated through several steps.

A power system having three generators and an average load are considered by Qamber and Al-Hamad in their study [8]. The objective of the study is to find the LOLE. Furthermore, a Reserve Margin in their study [8] is determined as a target generation margin. This study is to find the system reliability and an example [8] solved.

2. NEURO-FUZZY MODEL

Some terms are used in the Fuzzy Logic. These terms are understood by the human language. These terms convey the system information and combine this information with the Neural Networks advantages. The combination permit both of interaction between the human operator and considered system under study. The data trained using the ANFIS, the results are found. The model inputs are two. These two are both the Generation and Load Model data.

The Fuzzy values represent the input data, where the output is known as LOLE of the system. Using the Neuro-Fuzzy to train the input data of the considered system. The trained data is targeting the suitable predicted results values which is based on the relationship of the trained period. When the output set mapped to crisped values, this means that the defuzzification technique process is applied. Finally, and after the training of the input data using the Neuro-Fuzzy, it is found that the developed model provides a suitable and reasonable output LOLE values using the ANFIS application.

As a rule-based Neural Network structure, the multi-layer is utilized in the present study. I addition, the firing strength vector is up-dated by the minimization of the Neuro-Fuzzy weight [9-11] and finding:

$$v^x = \frac{v_r}{\sum_{i=0}^{m} v_i} \tag{1}$$

A step amount and weight space direction found using the Newton Algorithm, where the Algorithm is used as a help to find the cost function J_N (v) through its minimum. The firing strengths of the Fuzzy rules is v^x.

The cost function might be approximated by the quadratic function using Taylor's expansion:

$$J_N(v + \Delta v) = J_N(v) + \Delta v \frac{dJ_N(v)}{dv} + \frac{1}{2} \Delta v^T \frac{d^2 J_N(v)}{dv^2} \Delta v \tag{2}$$

As a definition, the updated weight vector Δv is defined as the weight vector v and T defined as the transpose. Finding the differentiation and minimization of equation (2), where it is set equal to zero to find the following results:

$$\frac{dJ_N(v)}{dv} = \frac{d^2 J_N(v)}{dv^2} \Delta v \tag{3}$$

$$g = -H \, . \, \Delta v \tag{4}$$

where:

g is the gradient of $J_N(v_k)$, and

H is the Hessian of $J_N(v_k)$

Using the Newton's equation to find the solution to the equation which is a combination of a gradient algorithm. Hence, the algorithm is defined as:

i) k = zero

ii) v_k. is called the initial weight vector.

iii) $g(v_k)$ the gradient and $H(v_k)$ Hessian are functions of the weight.

iv) Applying the termination of $\|g(v_k)\|$ through the condition that it will be less than $\in$

v) In case of $\| v_{k+1}\| \leq D_k$: solving $H(v_k)\, \Delta v_k + g(v_k)$ following a conjugate gradient.

vi) Starting with λ_k=1and under the condition $v_{k+1} = v_k + \lambda_k \Delta v_k$., we can calculate λ_k

The (D_{k+1}) is adjusted with the following:

$$D_{k+1} = \begin{cases} 2D_k & if \quad \lambda_k \geq 1 \\ \frac{D_k}{3} & if \quad \lambda_k < 1 \end{cases} \tag{5}$$

vii) Back to step (iv).

Both $g(v_k)$ and $H(v_k)$ are required to $J_N(v_k)$. Later, consider v and the derivatives of $J_N(v)$, where we can find the following:

$$\frac{\partial J_N(v)}{\partial v_p} = \frac{1}{N}\sum_{k=1}^{N} 2\frac{\partial \hat{y}(v(k),v)}{\partial v_p}\left[y(k) - \hat{y}(v(k),v)\right] \tag{6}$$

$$\frac{\partial^2 J_N(v)}{\partial v_p \partial v_q} = \frac{1}{N}\sum_{k=1}^{N}\left[2\frac{\partial^2 \hat{y}(y(k),v)}{\partial v_p \partial v_q} y(k) - \hat{y}(v(k),v) + 2\frac{\partial \hat{y}(v(k),v)}{\partial v_p}\frac{\partial \hat{y}(v(k),v)}{\partial v_q}\right] \tag{7}$$

Finally, finding:

$$\frac{\partial \hat{y}(x,v)}{\partial v_p} = \begin{cases} \mu_{A^i}^{u} \\ \left[\prod_{u=1,u\neq k}^{U}\sum_{i=1}^{P_u}\mu_{A^i}^{u} v_i^u\right]\mu_{A^j}^{k} \end{cases} \tag{8}$$

Firing strengths v_i^u relates to the i[th] weight of u[th] tensor model.

$$\frac{\partial^2 \hat{y}(x,v)}{\partial v_p \partial v_q} = \begin{cases} \left[\prod_{u=1,u\neq m\neq k}^{U}\sum_{i=1}^{P_u}\mu_{A^i}^{u} v_i^u\right]\mu_{A^j}^{k}\mu_{A^l}^{m} \\ 0 \end{cases} \tag{9}$$

3. NEURO-FUZZY DEVELOPMENT MODEL

The ability of exchange between the main grid system and microgrids might be defined as a concept of the smart grid infrastructure of the microgrids. The applied method helps in the study as a tool to find the system's performance over time or after an improvement has been made if it is operating or fail. In addition, the index term LOLE is power system reliability well known index. Furthermore, this index is helping in the reliability analysis of the power system.

The ANFIS is followed and applies the Artificial Neural Network (ANN). The developed ANFIS model is illustrated and represented by Fig. (1).

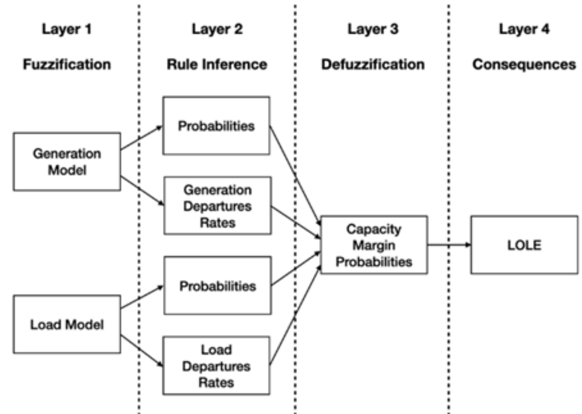

Fig. (1) N-Fuzzy Development Model

The LOLE is controlled by FIS, where two inputs are cleared through the first layer. Both of generation and loads are considered as two inputs for the first layer, where the second layer procedure is the conversion of output fuzzy set into step to output which is a single value. The Capacity Margin Probabilities are the results obtained in Layer 3. Furthermore, the LOLE is obtained with relationship of the Capacity Margin Probabilities which reached the fourth layer as LOLE. Therefore, the LOLE is the output of the procedure.

Fig. (2) shows the generation model represented by three generating units. Each generating-unit has 200MW capacity, where the repair rate and failure rate are 0.45 repair per year and 0.05 failure rate, respectively. Fig. (3) shows the load model which represented by four cases of average peak loads 0.45GW, 0.3GW, 0.15GW, and 0GW. The number of occurrences of each average peak load are 3, 5, 7, and 0, respectively. The model exposure factor € is 0.5, where the Exposure Factor (EF, e) is known as the power loss. As a definition, the Exposure Factor is known as the ration of two values. These values are the Single Loss Expectancy and Asset Value. Both values have a symbols SLE (Single Loss Expectancy) and AV (Asset Value), respectively. Therefore, the Exposure Factor formulae is:

$$EF = e = \frac{SLE}{AV} \tag{10}$$

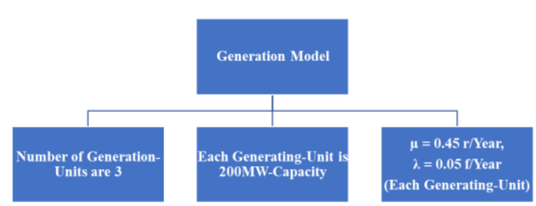

Fig. (2) Generating-Units Model Representation

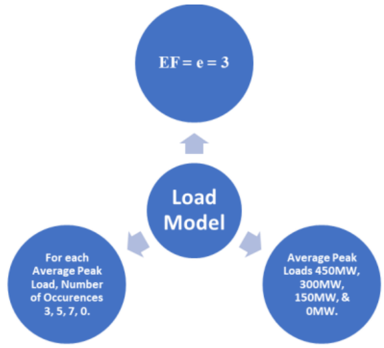

Fig. (3) Load Model Representation

The four states model of the system represented by both Fig. (4) and Table I.

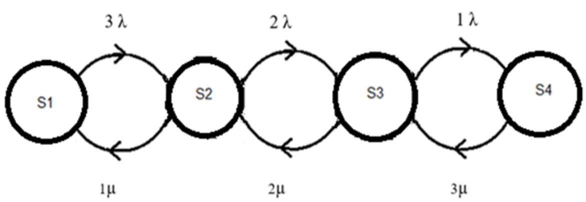

Fig. (4) Four States Model

TABLE I. FOUR-STATE SYSTEM

Transition Rates	***From (S1)***	***From (S2)***	***From (S3)***	***From (S4)***
To (S1)	-0.85	0.45	0	0
To (S2)	0.15	-0.45	0.9	0
To (S3)	0	0.1	-0.05	1.35
To (S4)	0	0	0.05	-0.35

Applying the binomial distribution, where the available generators are 3 generating-units, p = 0.9 and q = 0.1:

$$P(No.of\ Success) = \frac{n!}{r!\ (n-r)!}\ p^r\ q^{(n-r)} \qquad (11)$$

The output results are becoming as illustrated in Table II.

TABLE II. THREE GENERATING-UNITS RESULTS

r!	p^r	$q^{(n-r)}$	Indiv. Prob	Cumulative Prob.
6	0.729	1	0.729	1
2	0.81	0.1	0.243	0.271
1	0.9	0.01	0.027	0.028
1	1	0.001	0.001	0.001

The results of both the generating-units and the average peak load are shown in Table III and Table IV, respectively.

Fig. (5a) illustrates the relationship of the generation model results obtained as a Pie-shape. It shows the results obtained in slices. The capacity IN represented by the individual probabilities, where four capacity IN in (MW) considered in the present study. The 600MW capacity IN has the highest value of the probability and represented as the selected Capacity IN case with 72.9% probability of this model. In addition, this case means that the three generating units are under success operation. In case that the success becomes 2 generating units, the probability becomes 24.3%. The same model is shown in another form known as a radar shape which shown in Fig. (5b). Fig. (5c) shows the four-states model with 3, 2, 1, and 0 as the generating-units number of success. Fig (5c) illustrates the histogram which represents the quality control tool that graphically displays a data set. In addition, this time the results are represented by the cumulative probabilities instead of individual probabilities of the model. Based on the obtained results the reliability of the model is 99.9% which means that the system has a high reliability value.

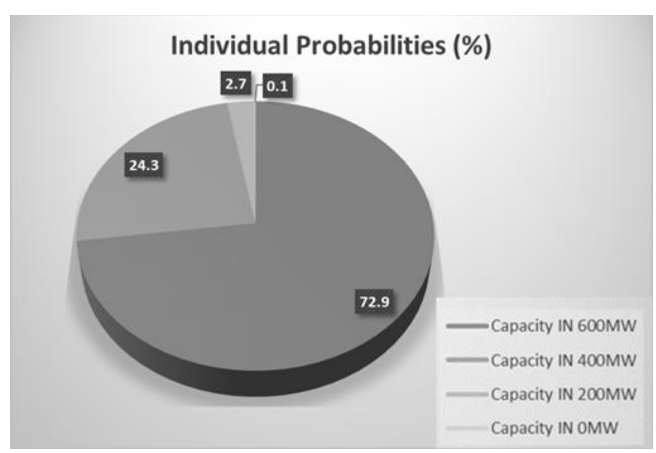

Fig. (5 a) Generation Model Results

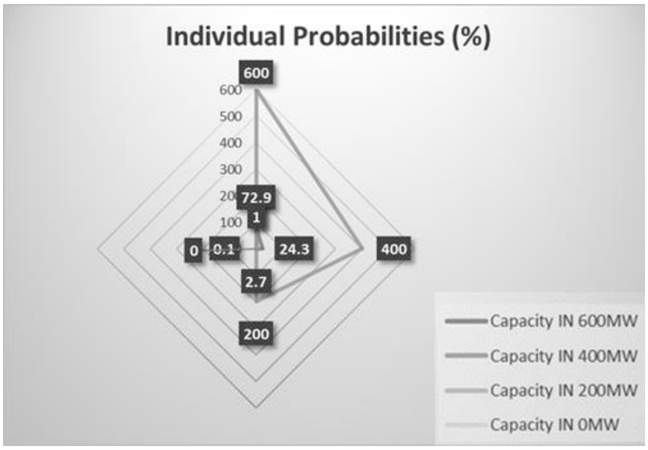

Fig. (5 b) Radar, Generation Results

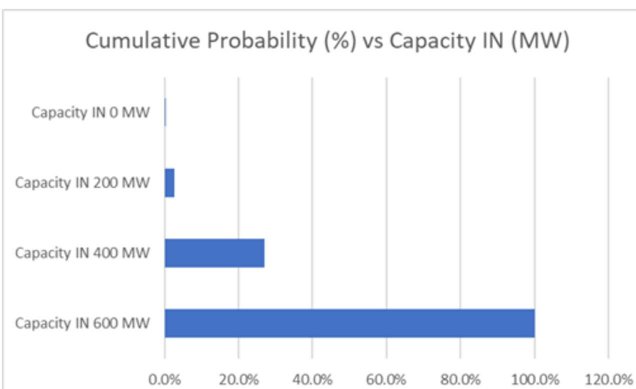

Fig. (5 c) Generation Model, Cumulative Probabilities vs Capacity IN (MW)

Fig. (6) shows the variation of the average peak load versus number of occurrences of the load in percentage. The highest value of the average peak load which is 450MW has the highest number of occurrences which is 46.67%. Then 300MW has the mid value of percentage which is 33.33%. It followed by the lowest percentage which is 20%.

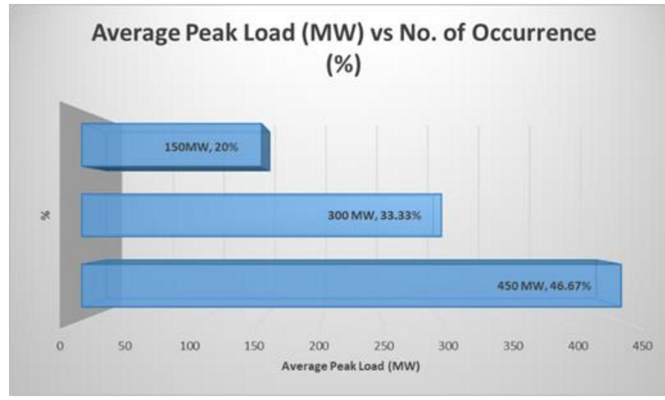

Fig. (6) Load Model Results

The capacity margin is known as reserve margin [1]. The CMP results stored in Table V. Fig. (7) shows the relationship of the annual probability which variate with the capacity margin, where the margin is defined as the difference between the available capacity and the system load. The load creates a set of discrete capacity margins. It is clear from Fig. (7) that is has a negative as well as positive margin. The negative margin represents the case that the load of the considered system exceeds the available capacity. This negative margin shows a system failure condition. It should be known that the transition from one margin state to another illustrated in both Table (V) and Fig. (7) might be made by a change in capacity of the system or a change in load, but not by both. In addition, the results shown in Fig. (7) shows both the variation of both the annual probability versus the capacity IN. At the same time, it illustrates the relationship as a linear relationship of both the annual probability versus the capacity IN (MW).

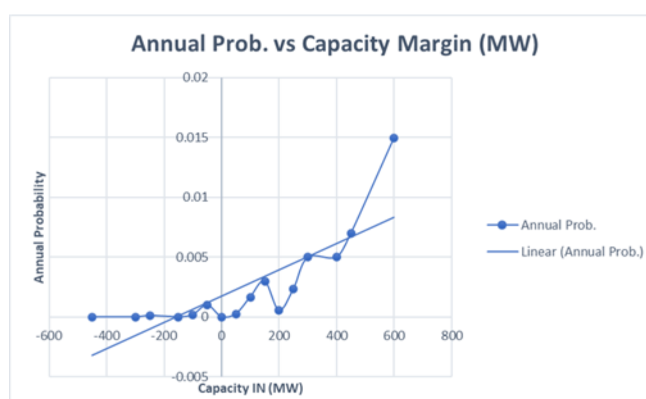

Fig. (7) Annual Prob. vs Capacity Margin

The equation of Reserve Margin is:

$$Reserve\ Margin = \frac{Capacity - Demand}{Demand} \quad (12)$$

Combining the available capacity and electric load will form a set of capacity margins (m_k). As a definition, both of electric load and available capacity of the considered system are:

$$m_k = P_c - L_i \quad (13)$$

$$P_k = P_c * P_i \quad (14)$$

$$\lambda_{+m} = \lambda_{+n} + \lambda_{-L} \quad (15)$$

$$\lambda_{-m} = \lambda_{-n} + \lambda_{+L} \quad (16)$$

In annual basis, the CMP and LOLE are determined. The integration of the generation and load models are shown in Table VI. Therefore, the LOLE is calculated:

$$LOLE = \left(\begin{array}{c} Cumulative\ Probability\ of \\ the\ first\ negative\ Margin \end{array} \right) \text{ x } \frac{365}{e} \quad (17)$$

A question raised about the form of the LOLE equation with its relation with LOLP. Therefore, the relationship is:

$$LOLE = LOLP \text{ x } 8760 \quad (18)$$

Table VII summaries the results of Generation probabilities per year. Therefore, as a sample of the results, the LOLE value is 0.026 days per year. This result is equivalent to 0.622 hours per year.

For any country, the developed model in the present study can be used. The Neuro-Fuzzy technique is followed to develop the required model. This means that the value of LOLE as a targeted lowest value can be obtained for the generation-load model. In reference [1], Qamber considered three genrators and average loads to find the LOLE value through his study. Furthermore, in the studies [1,11] the emergency margin is well defined and calculated for the electric power system reliability as a production target limit.

In his book [1], Qamber explained the targeted power generated margin which is considered as a critical criterion applied to find the system reliability. As a comparison between Qamber [1] in his book and Čepin in the study [4] found that LOLE described in Qamber's study the LOLE has a unit of days per year. Qamber in his book [1] addresses both of LOLE and LOLP. The LOLE is expected when the capacity does not increase enough to load reach a daily maximum, where Čepin presented the value for power plants that LOLE determined for power plants progressively recovering more compact energy sources. In addition, Čepin [4] analyzes the power plants of nuclear and wind. Also, a comparison of different scenarios of the power reliability considerations.

Moghaddam et al [2], in their study examined the management for both hybrid systems and the optimal energy design. In their study, the photovoltaic panels are considered. Also, wind turbines and fuel cells based on hydrogen storage are discussed. In addition, in their study Moghaddam et al [2] they take in their consideration the power system reliability indicators of LOLE and the expected energy loss expectation. The value of the loss is determined based on the average net hourly wage ($). Therefore, to assess the reliability of electric power system [6,7] the loss value needs to be calculated.

The criteria of calculating the LOLE normally expressed as the amount of days/year, where it is complex metric might account for the dynamic power system. This means that the generation resources become insufficient to reach the required load demand. In addition, the Criteria forms a good target, but at the same time might create lousy planning/compliance measure. In the present study, the obtained value of LOLE is 0.026 days per year which is equivalent to 0.622 hours per year. This value is considered as accepted value. In case that the daily peak demand exceeds the available generating capacity the LOLE is required to be calculated. Therefore, the LOLE is defined as the ability of a system's resources to cover a required load demand. The planning reserve margin is simple and static at the same time. Furthermore, the planning reserve margin is easy to be considered and used as benchmark for planning and compliance. The planning reserve margin is defined as a probabilistic measure.

4. CONCLUSION

The reliable power system network is obtained using the developed Neuro-Fuzzy model in the present study. In addition, the developed model is helping to reduce both of black-out and load shedding cases. Furthermore, the study found the most suitable reliable values of the developed Neuro-Fuzzy. The most reliable value targeted in the study is the LOLE. The LOLE value calculated is low which is equal to 0.622356164 hours per year. The study is helping to avoid the coming future generation capacity in. The procedure helps the researcher targeting the countries to obviate load shedding and at the same time satisfying the reasonable energy demand for different sector(s). Finally, it should be noted that the developed Neuro-Fuzzy model helps in the country's economic development.

ACKNOWLEDGMENT

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TABLE III. GENERATION RESULTS

State	Capacity IN (GW)	Capacity OUT (GW)	Ind Prob (%)	Departure λ_{+n}	Rate λ_{-n}	Frequency (%)	P (%) (Annual)	Cum Prob (%) (Annual)	Cum Freq (%)
First	0.6	0	72.9	0	0.15	10.935	2.99589041	4.109589041	0
Second	0.4	0.2	24.3	0.45	0.1	13.365	0.99863014	1.11369863	10.935
Third	0.2	0.4	2.7	0.9	0.05	2.565	0.1109589	0.115068493	2.43
Fourth	0	0.6	0.1	1.35	0	0.135	0.00410959	0.004109589	0.135

TABLE IV. AVERAGE PEAK LOAD RESULTS

State	Average Peak Load L_i (GW)	Occurrence n_i	Probability, P $= \frac{ni\ e}{D}$	Annual P = $P\left(\frac{10}{365}\right)$	Departure λ_{+L}	Rate λ_{-L} =1/e
1	0.45	3	0.1	0.004109589	0	2
2	0.3	5	0.166666667	0.006849315	0	2
3	0.15	7	0.233333333	0.009589041	0	2
0	0	Σ 15	1-e 0.5	Σ 0.020547945	$\frac{1}{1-e}=$ 2	0

TABLE V. ANNUAL PROBABILITY OF CM

Margin (in GW)	Annual Probability	
0.6	14.97945E-03	
0.45	6.990411E-03	
0.4	4.993151E-03	
0.3	4.993151E-03	
0.25	2.330137E-03	
0.2	0.554795E-03	7.878082E-03
0.15	2.995890E-03	
0.1	1.664384E-03	
0.05	0.258904E-03	
0.0	0.205479E-04	
-0.05	0.9986300E03	First Negative Margin Value
-0.1	0.1849320E-03	
-0.15	0.9589040E-05	
-0.25	0.1109590E-03	
-0.3	0.6849320E-05	
-0.45	0.4109590E-05	6.254795E-03

TABLE VI. COMBINATION OF GENERATION-LOAD

	Electric Load	1	2	3	0
	L_i (GW)	0.45	0.3	0.15	0.0
	P_i (%)	0.4109589	0.6849315	0.9589041	2.0547945
	λ_{+L}	0	0	0	2
	λ_{-L}	2	2	2	0
	Generated Power				
n = 1, Capacity (GW) =	**0.6**	0.15	0.3	0.45	0.6
P_1 (%) =	**72.9**	0.299589	0.4993151	0.6990411	1.4979452
λ_{+n} =	**0**	2	2	2	0
λ_{-n} =	**0.15**	0.15	0.15	0.15	2.15
n = 2, Capacity (GW) =	**0.4**	-0.05	0.1	0.25	0.4
P_2 (%) =	**24.3**	0.099863	0.1664384	0.2330137	0.4993151
λ_{+n} =	**0.45**	2.45	2.45	2.45	0.45
λ_{-n} =	**0.1**	0.1	0.1	0.1	2.1
n = 3, Capacity (GW) =	**0.2**	-0.25	-0.1	0.05	0.2
P_3 (%) =	**2.7**	0.0110959	0.0184932	0.0258904	0.0554795
λ_{+n} =	**0.9**	2.9	2.9	2.9	0.9
λ_{-n} =	**0.05**	0.05	0.05	0.05	2.05
n = 4, Capacity (GW) =	**0.0**	-0.45	-0.3	-0.15	0.0
P_4 (%) =	**0.1**	0.0	6.84932E-04	9.58904E-04	60
λ_{+n} =	**1.35**	3.35	3.35	3.35	1.35
λ_{-n} =	**0**	0	0	0	2

TABLE VII. GENERATION PROBABILITIES PER YEAR

Cap. IN (GW)	*Cap. OUT (GW)*	*Individual Prob (%)*	*Cum. Prob (%)*	*Annual Prob (%)*	*Annual Cumulative Prob (%)*
ON ON ON					
0.6	0.0	72.9	100	2.99589	4.109589
OFF ON ON					
ON ON OFF					
ON OFF ON					
0.4	0.2	24.3	27.1	0.99863	1.1136986
OFF OFF ON					
ON OFF OFF					
OFF ON OFF					
0.2	0.4	2.7	2.8	0.11095	0.1150685
OFF OFF OFF					
0.0	0.6	0.1	0.1	4.1095E-03	4.10959E-03

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